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THE INNERVATION OF THE BLADDER AND URETHRA: A REVIEW.

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Two regions of the spinal cord have been proved in all mammals to be associated with the channels which conduct afferent impulses from the bladder and urethra and send to these structures efferent excito-motor or inhibitor impulses. The anatomical extent of these regions and their exact limitations differ from individual to individual of each species, and more widely from species to species. In man the lower region, which may be spoken of as the sacral, is that associated with the origin of the fourth, third and second sacral nerve-roots, whilst the upper or lumbar is connected with the second and first lumbar, the twelfth and probably the eleventh thoracic nerve-roots.

Chapter I.—The Afferent Path to the Spinal Cord from the Bladder and Urethra.

Like all the other abdominal and thoracic viscera, the bladder is insensitive to numerous traumatic and other stimuli, whilst at the same time it is sensitive to rapid alterations in the tension of its wall. Any rapid increase in the tension of the vesical wall leads, in the intact animal, to the development of reflex changes and motor responses: and sensory impulses thus originated in addition affect consciousness. Impulses from the bladder of this nature, when few in number or small in degree, lead to the development of a sense of discomfort in the region of the pelvis: but when larger and much above the threshold of appreciated change, or if nearer the threshold frequently repeated, produce that alteration in our consciousness which we speak of as pain. Visceral pain, as Ross [49] first suggested and subsequently Head [22] and Mackenzie [38, 39] more fully worked out, as soon as it can be localized, is "referred" to somatic parts and is felt by the patient as if it originated from the nerves of the body wall or from the sense-organs in the musculature of the trunk and extremities whose afferent nerve-fibres end in the same segments of the spinal cord as do the affected incoming visceral channels.

The first definite evidence relating to the afferent paths from the ureters, bladder and urethra in man we owe to Head [22] in 1893. This author showed that lesions of the mucous membrane of the bladder, such as appear in the cystitis associated with vesical calculus or after the accidental use of carbolic acid lotion for washing out the bladder, lead to a complaint of pain referred along the distribution of the third and fourth (and occasionally of the second) sacral nerve-roots, and may

be accompanied by hyperalgesia of the areas of skin at the back of the thigh and around the anus from which these nerve-roots are the afferent channels. On the other hand, during states of prolonged distension or over-distension of the bladder, associated with obstruction at its outlet, when ineffectual contractions of the vesical musculature occur, the pains have a different character and are felt as diffused pain "referred" over the segmental areas of skin supplied by the eleventh and twelfth thoracic and first lumbar nerve-roots; the skin over the lower portion of the abdomen and front of the upper part of the thighs may become tender, and the lower segments of the abdominal wall may show "protective rigidity." Such evidence enabled Head to localize the afferent channels from the bladder as having intimate connections with the third and fourth, and to a less extent with the second, sacral nerve-roots on the one hand, and with the eleventh and twelfth thoracic and first lumbar nerve-roots on the other. Similarly he was able to show that the prostate and prostatic urethra are related to the tenth, eleventh (and twelfth) thoracic and *also* with the first, second and third sacral nerve-roots, and that the segments connected with the ureters are the tenth, eleventh and twelfth thoracic; he was, however, unable to establish any evidence for pain being referred along the sacral nerve-roots during affections of the ureters.

A second line of investigation which has yielded some further knowledge and confirmatory information on the extra-medullary course of afferent impulses originating in the urinary passages, has been the study of clinical examples of local disease and injuries affecting the sacral or the lower thoracic and upper lumbar nerve-roots in their intraspinal course, more especially disease and gunshot wounds affecting the cauda equina. Thus it has long been known that when a patient shows analgesia and other evidence of a local lesion of the contents of the spinal canal in the sacral region, even if the areas of skin corresponding to the segmental distribution of the third and fourth sacral segments be alone affected, he knows when he wants to pass water, but has no power of retaining it. As soon as a certain amount of urine has collected in his bladder, he feels he wants to make water, and immediately urine comes from him involuntarily. If, however, the distribution of analgesia points to a lesion above the ninth thoracic segment the passage of urine is not only an automatic but a completely unconscious act. At the present time a further study of cases of local injury to the contents of the spinal canal in these two regions resulting from war-injuries should enable a more certain statement to be made

upon the course of the afferent impulses between the urinary passages and the spinal cord in man.

In animals the peripheral afferent path has been investigated by various methods, of which section of the posterior (dorsal) nerve-roots with subsequent histological investigation of the peripheral nerves for degenerated fibres has proved the most valuable. Three pairs of nerves send branches to the bladder or urethra or to both, namely, the pelvics and the pudics from the sacral plexus, and the hypogastrics by way of the inferior mesenteric ganglia. All three nerves have been shown to contain both afferent and efferent fibres. All the afferent fibres have their nutrient centres in the posterior root-ganglia and no peculiarity serves to distinguish visceral afferent from somatic afferent fibres, such as exists on the efferent side. No afferent path has upon it a cell-relay and synaptic junction in the lateral or collateral chain of sympathetic ganglia. By the method of degeneration Langley and Anderson [34] have shown that in the cat the branches from the sacral plexus which go to form the pelvic nerves (nervi erigentes) contain as many as one-third afferent fibres, whilst two-thirds are efferent, and that each nerve contains more than 1,000 afferent fibres which proceed from the pelvic area. In the hypogastric nerves the respective numbers are as one afferent to ten efferent and only about 100 afferent fibres are present in all from the total area innervated [31]. The paucity of afferent nerve-fibres proceeding from the various viscera compared with the number in connection with somatic parts has been suggested by Langley [28] as the reason for the high threshold to sensory stimuli in these organs.

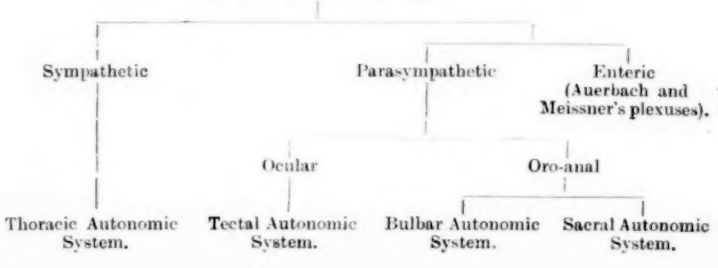
Further experimental evidence upon the course of the afferent fibres from the bladder has been sought in animals by noting the effects of section of the sacral posterior (dorsal) nerve-roots. Barrington [1], repeating Merzbacher's [40] experiments upon dogs, divided all the posterior sacral roots without damaging the anterior roots in cats and found that after the operation micturition was completely abolished, at any rate for twenty weeks, and that retention of urine associated with a lax condition of the bladder was permanently established. On the other hand, after removal of the inferior mesenteric ganglia or section of the hypogastric nerves he was unable to establish any gross interference with the sensibility of the bladder or urethra in the cat. Division of the pudic nerves in the cat renders the urethra anæsthetic and constantly produces some degree of incontinence of urine.

Chapter II.—The Efferent Path from the Spinal Cord.

Prior to the appearance of the epoch-making contribution of Gaskell [15] in 1886, knowledge of the origin, nature, course, structure, functions and intimate relations of the efferent channels for the innervation of the viscera was chaotic. But now, thanks in the main to the experimental and histological work of the Cambridge School of Physiologists, our knowledge of this system (the autonomic nervous system of Langley[1]; the involuntary nervous system of Gaskell) is as precise and definite as that of any other part of the body. Gaskell in 1886 laid down as the fundamental conception of the involuntary nervous system: "Three great outflows of fine medullated fibres to the peripheral motor ganglion cells, from the bulbar, thoracico-lumbar and sacral regions respectively, these three outflows being separated roughly from each other by the formation of nerve-plexuses for the upper and lower limbs; and in addition a smaller separate outflow from the mid-brain region" (Gaskell [16], p. 27).

"The involuntary nervous system," wrote Gaskell [16] in 1915, "is built up on the same plan as the voluntary nervous system, with receptor, connector and excitor elements. The marked difference is that the excitor elements have left the central nervous system and become peripheral, forming the various ganglia found throughout the body; while the receptor elements have remained in the same position as those of the voluntary system, namely, in the posterior root-ganglia, and connect by means of sensory root fibres with the cells of the connector elements, which have remained in the central nervous system; the connector fibres have passed out to reach their respective peripherally situated excitor elements. This outflow of connector fibres, at all events in the higher vertebrates, does not occur in every

[1] Langley [29] divides the autonomic nervous system thus:—



segment, but is interrupted at the places where the nerve-plexuses for the upper and lower limbs come in; so that we can speak of three outflows of these fibres, a bulbar, a thoracico-lumbar and a sacral. Of these the thoracico-lumbar outflow of connector nerves connects with all the excitor neurons of the so-called sympathetic system, the sacral outflow connects with another set of excitor neurons forming the pelvic ganglionic group, and the bulbar outflow connects with the excitor neurons found in the course of the various mesosomatic segmental

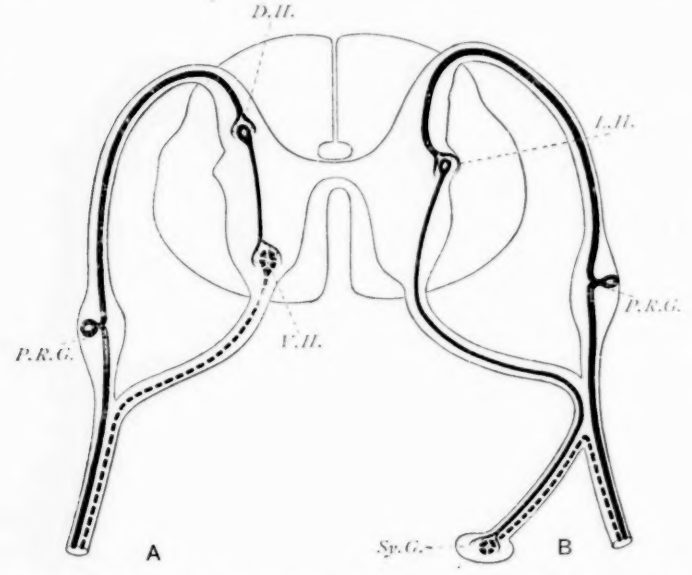


FIG. 1.—The reflex paths in the cord (after Gaskell [16]). **A**, of the voluntary system: The receptor neurons run in the posterior root (heavy black line), their cells lying in the posterior root ganglion, *P.R.G.* The connector neurons lie in the dorsal (posterior) horn, *D.H.*, and connect with the excitor neurons (dotted line) lying in the ventral (anterior) horn, *V.H.*, whose processes run in the anterior root. **B**, of the involuntary system: The receptor neurons (heavy black line) run in the posterior root, their cells lying in the posterior root ganglion, *P.R.G.* The connector neurons lie in the lateral horn, *L.H.*, their processes running out in the anterior root and connecting, as the white ramus communicans, with the excitor neurons (dotted line) lying in the sympathetic ganglia, *Sy.G.* The processes of the excitor neurons form the grey ramus communicans and run out in the spinal nerve.

nerves. In addition to these three main groups of connector nerves a fourth group exists confined to the region of the mid-brain which connects with the excitor neurons forming the ciliary ganglion. These

connector fibres leave the cord in the spinal region by the anterior roots, so that this root is made up of motor fibres to the voluntary system and connector (pre-ganglionic) fibres to the involuntary system" (Gaskell [16], p. 29).

From a series of experiments upon dogs, cats, rabbits, ferrets, monkeys and other mammals it is now absolutely certain that the bladder is supplied by two sets of efferent nerves. The first set are derived from the lowest thoracic and upper lumbar nerve-roots; they send their fibres by way of the white rami communicantes and the lumbar or inferior splanchnic nerves to the lumbar portion of the collateral sympathetic chain of ganglia which lies in intimate relations with the abdominal aorta and its branches. They then join the inferior mesenteric ganglia and, finally, by way of the hypogastric nerves reach the hypogastric plexus and the bladder. The second set of nerves to the bladder originate in the roots of the sacral nerves; from these roots two branches are given off, known as the *nervi erigentes* (Eckhard), the *pelvic splanchnics* (Gaskell) or the *pelvic nerves* (Langley), which run to the vesical part of the hypogastric plexus and so supply the unstriped muscle of the bladder, the urethra, and the corpora cavernosa, whilst the two pudic nerves form the motor path to the striped voluntary muscle of the urethra.

(*a*) *The sympathetic nervous supply.*—Investigations by Gaskell Langley and Anderson, and others have shown that (1) all the nerves derived from the spinal cord between the origin of the first thoracic and second and third (or fourth) lumbar nerve-roots—the lowest nerve varying slightly in different animals, and more widely in different species—possess a white ramus communicans containing preganglionic fibres, which are efferent in function; (2) that the nerve-fibres contained in this white ramus before reaching their effector organ meet a cell-relay and form synaptic junctions with cells contained *either* in one or more of the lateral chain of sympathetic ganglia *or* in some part or parts of the collateral prevertebral chain; (3) that in general each preganglionic fibre is connected by means of collateral branches with several ganglionic cells in the sympathetic chain, but that between any connector cell in the central nervous system and the effector organ in the periphery only one cell-station is intercalated. "Each sympathetic ganglion is, broadly speaking, a cell-station for all classes of visceral fibres which supply a definite area" (Langley [27]); (4) that every spinal nerve shortly after leaving the spinal cord receives an accretion of fibres from the lateral sympathetic chain of ganglia as a grey ramus

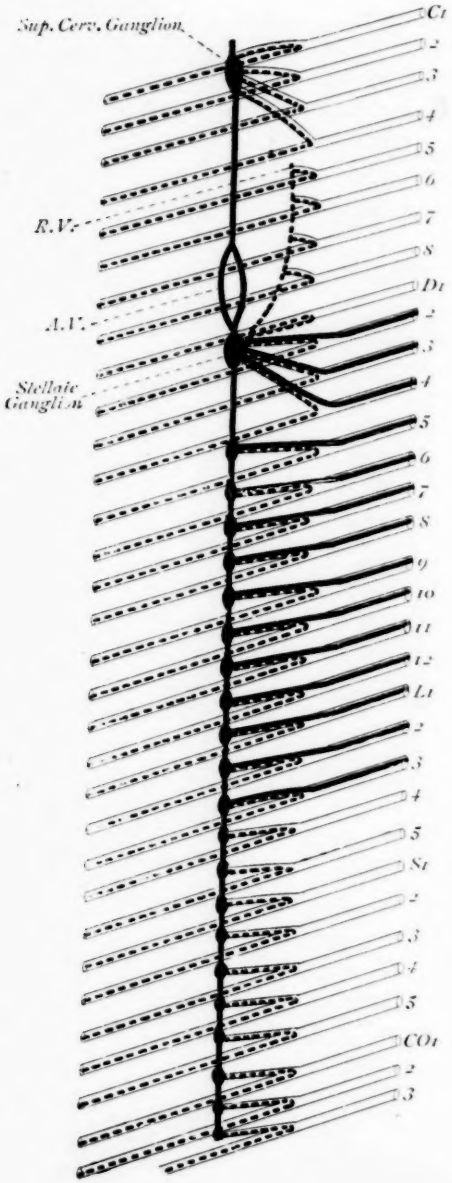


FIG. 2.—The arrangement of the connector fibres (thick black lines) and the excitor neurons (dotted lines) of the sympathetic system in the spinal region [after Gaskell [16]]. All the spinal nerves are shown from the first cervical, *C* 1, to the third coccygeal, *CO* 3. All the connector neurons leave the spinal cord in the thoracico-lumbar outflow which extends from the second dorsal, *D* 2, to third lumbar, *L* 3. The lateral chain of sympathetic ganglia is connected together by the further prolongation of these processes which run from ganglion to ganglion, connecting in three or more of them with the cells of excitor neurons. The lateral chain is therefore made up of a series of groups of excitor neurons connected together by the processes of connector neurons. Certain ganglia have become fused, those corresponding to the first four cervical nerves being aggregated into superior cervical ganglion, those of the last four cervical and the first four dorsal being aggregated into the stellate ganglion, which lies just caudal to the annulus of Vieussens, *A.V.* For the sake of simplicity the ganglia on this annulus and the inferior cervical ganglion have been omitted and considered part of the stellate ganglion. The processes of the excitor neurons belonging to any ganglion run out in the grey ramus communicans to join the spinal nerve and to be distributed with it. The excitor fibres for the first four cervical nerves thus arise from the superior cervical ganglion, the excitor neurons for the last four cervical nerves arise from the stellate ganglion, and at first all run in the ramus vertebralis, *R.V.*; they finally branch from this and join their respective nerves. Similarly the excitor fibres of the first four dorsal nerves, all arise from the stellate ganglion, to which the first three white rami communicantes run. The rest of the spinal nerves are supplied with sympathetic excitor fibres from their corresponding sympathetic ganglia.

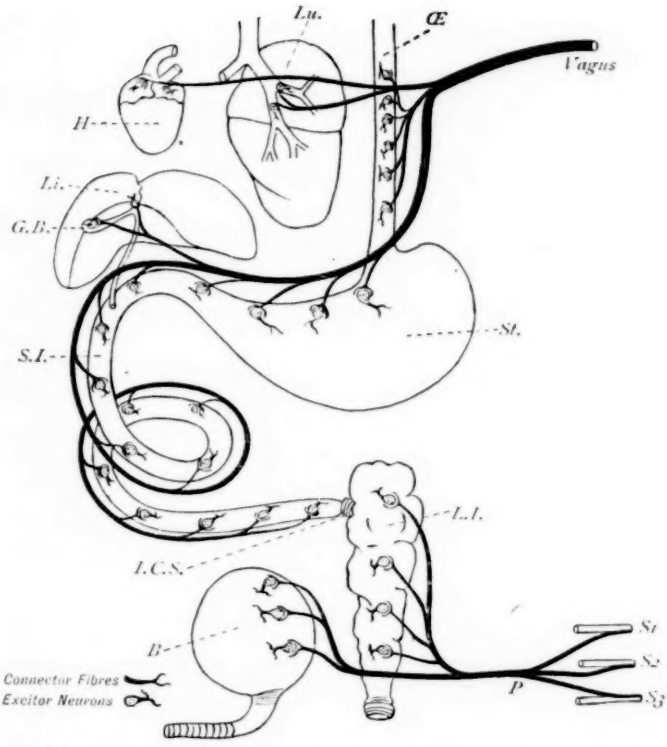


FIG. 3.—The distribution of the connector fibres (thin black line) and excitor neurons (dotted areas) of the bulbo-sacral or enteral system after Gaskell [16]. The vagus nerve contains the connector nerves of the excitor neurons of the main viscera as far as the ileo-colic sphincter, *I.C.S.* The motor neurons all lie on the organs themselves. The pelvic nerve, *P.*, contains the connector fibres of the sacral outflow and connects with peripheral excitor neurons on the large intestine and bladder. The vagus nerve thus contains the connector neurons to the motor cells of the heart, *H.*, which have to do with the slow wave-like contraction which is only found in certain tortoises, such as *Emys europea*, and does not appear to exist in higher forms. The vagus nerve also contains the connector fibres to the excitor neurons on the bronchi in the lung, *Lu.*, and also the connector fibres to the excitor neurons on the gall-bladder and bile duct lying on the liver, *Li.*: it also contains the connector fibres to the excitor neurons of the œsophagus, *Œ.*, the stomach, *St.*, and the small intestine, *S.I.*, which here lie between the muscle layers in Auerbach's plexus. The pelvic nerve, *P.*, which arises from the three sacral roots, *S* 1, 2, and 3, contains the connector fibres to the excitor neurons of the large intestine, *L.I.*, and also the connector fibres of the excitor neurons of the body of the bladder, *B.*

containing post-ganglionic effector fibres; (5) that the motor nerves for the muscles of the blood-vessels of the whole body belong to this system of nerve-fibres; (6) that the motor nerves to the sweat-glands and, for all unstriped muscle under the skin, whether pilomotor or not, belong to this system: (7) that the motor nerves to the sphincters of the intestine (ileo-colic at the end of the small intestine (Elliott [9]), internal anal sphincter (Langley and Anderson [34]) at the end of the coprodœum (Gaskell [16], p. 44), internal vesical sphincter and urethral muscles (Elliott [11]) at the end of the urodœum (Gaskell [16], p. 44), belong to this system; (8) that the motor nerves to the involuntary muscle derived from the parts surrounding the Wolffian and Müllerian ducts (segmental duct system of Gaskell [16], p. 40), belong to this system; (9) that the substance adrenalin (adrenine, epinephrin) whose actions were first systematically investigated by Oliver and Schäfer, and which was first isolated by Takamine [59], acts *only* on those tissues which are innervated by this "sympathetic" nervous outflow of efferent fibres, and that its action is always the same as that of excitation of the sympathetic nerves supplying the tissue (Elliott [10]); (10) that motor and inhibitor nerves both occur within the class of sympathetic nerves: (11) that the substance ergotoxin derived from ergot possesses the remarkable property of paralysing *only* the motor fibres of the sympathetic system (Dale [7]); (12) thus in the case of any particular muscle group, supplied with motor and inhibitor nerve-fibres from a combined motor and inhibitor sympathetic nerve, stimulation or the application of adrenalin gives only motor effects; but after the injection of ergotoxin, stimulation or adrenalin will produce inhibition, not contraction.

(*b*) *The sacral autonomic nervous supply.*—Concerning the general problems of this innervation, investigations have shown: (1) that physiologically speaking the bulbar and sacral outflows of efferent visceral fibres (the oro-anal portion of the autonomic nervous system of Langley) are mutually supplementary and together supply motor control to a single system of involuntary unstriped musculature belonging to the alimentary canal and its embryological and morphological derivatives—a system which may be spoken of as *endodermal* (Gaskell [16], p. 63). The vago-accessory outflow supplies the upper part of the digestive tract and its derivatives (œsophagus, stomach, small intestine, liver and gall-bladder, lungs, heart, &c.), and the pelvic outflow the lower part of the digestive tract and its derivatives, including the whole of the large intestine, the rectum, the bladder and the urogenital tract. (2) The

connector cells of this system, whose axons form long connector fibres to the peripherally placed ganglion cells, all lie inside the central nervous system, whilst the effector post-ganglionic fibres are extremely short, the ganglionic cell itself lying close against the musculature which it supplies; (3) that the pelvic nerves do not pass into well-defined ganglia, but pass instead into a nerve-plexus which extends over the surface of the bladder and rectum and so may be divided roughly into vesical and rectal portions. From this plexus post-ganglionic effector fibres pass to supply the large intestine, bladder and urogenital tract. Each pelvic nerve divides primarily into an

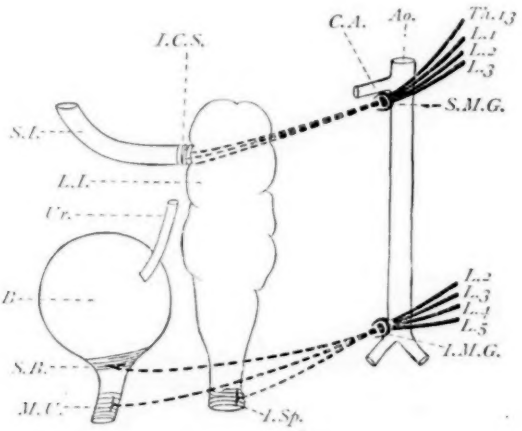


FIG. 4.—The connector fibres and excitor neurons of the sphincter system of involuntary muscles (after Gaskell [16]). The figure shows their arrangement in the mammal. The connector neurons form two groups; an upper group rising from the last dorsal and first three lumbar roots and all running to the superior mesenteric ganglion, *S.M.G.*, which lies at the point of origin of the coeliac axis, *C.A.*, from the aorta, *Ao.*, and a lower group rising from the second to fifth lumbar roots, *L.2* to *L.5*, and running to the inferior mesenteric ganglion, *I.M.G.*, which is situated just above the bifurcation of the aorta. The excitor neurons from the superior mesenteric ganglion innervate the ileo colic sphincter muscle, *I.C.S.*, which lies at the junction of the small intestine, *S.I.*, and the large intestine, *L.I.* The excitor neurons in the inferior mesenteric ganglion supply in the mammal the internal sphincter muscle, *I.Sp.*, the sphincter of the bladder, *S.B.*, and the muscle of the urethra, *M.U.*

anterior and a posterior branch. The posterior branch connects with the rectal plexus, from which arise nerves running directly into the intestinal wall: these nerves Langley and Anderson [33] speak of as the sacral colonic nerves in contradistinction to the lumbar colonic nerves arising from the inferior mesenteric ganglia. The anterior

branch connects with the vesical plexus in which lie the motor cells to the bladder. All such motor cells lie in a plexiform arrangement upon the surface of the musculature they supply. (4) The substance obtained by Dale from ergot, and identified by Ewins [8] as acetylcholine, when injected intravenously in minute doses, picks out the nerves of the bulbar and sacral outflows and produces the same effects as electrical stimulation of the bulbar and sacral connector nerve-fibres, just as adrenalin when injected intravenously produces the same effect as stimulation of the thoracico-lumbar connector nerves.

(*c*) *The central nervous origin of the efferent paths.*—The thoracic region of the spinal cord is distinguished from regions immediately above and below by the presence of two distinct groups of nerve-cells, of which one forms the large cells of Clarke's column, and the other a noteworthy lateral horn with small cells. Gaskell [15] in 1886 pointed out that the distribution of these two groups of nerve-cells corresponds closely with the distribution of the preganglionic connector fibres in the white ramus communicans running to sympathetic nerve-cells, and suggested that the cells of the lateral horns gave rise to these connector fibres. Anderson proved the truth of this suggestion in the case of the cells whose fibres pass into the cervical sympathetic nerves. This author cut the cervical sympathetic nerve on one side in young kittens and allowed the animals to grow up; he then found histologically a gross difference in the number of the cells of the lateral horn column of the two sides in this region. The side on which the cervical sympathetic upper thoracic nerve had been previously cut showed many fewer cells than the intact side. Many observers since have come to the same conclusion, so that this column is now universally considered to give origin to the connector fibres to the neurons of the sympathetic system.

In the sacral region of the spinal cord a distinct mass of cells is found situated laterally on the edge of the grey-matter and appears to bear the same relation to the connector fibres of the pelvic nerve as these cells in the lateral horn of the thoracico-lumbar region to the connector fibres of the sympathetic outflow. Moreover, Elliott by Nissl's method of chromatolysis has shown that changes in the position of the nucleus of each of these cells can be constantly observed after peripheral section of the pelvic nerve in the cat. But as yet no other evidence upon these connections has been recorded, and we cannot speak with absolute certainty of the position in the central nervous system of these sacral efferent neurons. Elliott [11] by dividing the spinal cord at the level of the last lumbar nerve-root showed that none of these sacral lateral

horn cells sends fibres to the lumbo-thoracic splanchnics, and concluded that the cells of the spinal cord which give origin to the pelvic nerves lie in the sacral segments below the lumbar enlargement. Thus it is probable that the cells which give rise to the connector fibres of the thoracico-lumbar outflow are strictly confined to the same portion of the spinal cord, and that the corresponding cells of the sacral region give origin entirely to the connector pelvic nerves.

Langley and Anderson [32] have shown that the superficial origin of the vesico-motor fibres from the spinal cord varies with the origin of the somatic nerves. In the cat with an anterior arrangement (pre-fixation of somatic nerves), the 1st sacral has vesico-motor fibres and it may carry more of these fibres than the 3rd sacral. With a posterior arrangement (post-fixation), the 3rd sacral may be more effective on the bladder than the 2nd; in the majority of investigations the 2nd sacral nerve carried most of the vesico-motor fibres.

(*d*) *The tracts in the central nervous system connected with the efferent paths.*—Upon the exact anatomical course of the tracts within the central nervous system by which are carried impulses concerned with the voluntary control of micturition, little is known accurately. Budge in 1864 [4] showed that in animals it is possible by means of electrical stimulation of the spinal cord to trace paths which act upon the nervous control of the bladder upwards through the medulla oblongata as far as the cerebral peduncles. Valentin in 1839 proved that excitation of certain portions of the brain, especially of the cerebral peduncles, the corpora striata and the optic thalami, provokes movements of the bladder. Certain experiments of Mosso and Pellacani [41] indicate that the cerebro-vesical paths run in the posterior segment of the spinal cord. In the dog, Bechterew and Mislawski [2], and Frankl-Hochwart and Fröhlich [13], showed that electrical stimulation of the sigmoid gyrus behind the external extremity of the sulcus cruciatus produces contractions of the bladder, and Sherrington in monkeys also found a "cortical centre" which, on stimulation, caused changes in the musculature of the bladder (Luciani [37]). Stewart [58] showed that cerebro-vesico-motor impulses passing down one half of the spinal cord are not grossly affected in their conduction by a section down the mesial line of the cord *below* the origin of the first cervical nerve-root and *above* the upper lumbar segments. On the other hand, this author found that such a mesial section between the lower point of the external origin of the 2nd lumbar and the lower point of origin of the 5th lumbar nerve-roots caused gross interference with the conduction of impulses to

the bladder originating in the cerebrum. From his experiments he was further led to conclude that: (*a*) the path in the spinal cord for all impulses lies in the posterior (dorsal) part of the lateral columns. This path conducts both impulses of cerebral origin together with those which originate from sensory stimuli entering the spinal cord by segments above those which give rise to connector fibres to the inferior mesenteric ganglia; (*b*) that impulses excited reflexly or from electrical stimulation of the spinal cord in the cervical or thoracic regions can cross from one half of the cord to the other in the lumbar region; (*c*) that impulses set up reflexly by way of the sacral roots can cross the spinal cord in the sacral region.

In man, pathologico-clinical investigations have also suggested that the cerebro-vesical path lies in the posterior portion of the lateral columns of the spinal cord near to the pyramidal tract. For whenever both crossed cortico-spinal paths are affected in the cervical or thoracic regions of the spinal cord, as in the so-called pressure myelitis (e.g., in association with tuberculous disease of the vertebræ or with extra-medullary spinal tumour), in disseminated sclerosis, in subacute combined degeneration of the cord, in hæmatomyelia, in syringomyelia, &c., voluntary control over micturition is affected. Czyhlarz and Marburg [6] collected a series of clinical cases from the literature to prove that a "cortical bladder centre" exists in man and lies in the Rolandic motor area between and in close association with both the leg and the arm "centres"; it sends its fibres to a second "centre" in the corpus striatum, and connects also with a third "centre" in the optic thalamus. They stated further that, "es ist wahrscheinlich dass dem Kleinhirn ein gewisser Einfluss auf die Miction zufällt," but their evidence is far from convincing. Friedmann [14], in 1904, reported the case of a child in whom a circumscribed lesion in the upper third of the posterior central convolution led to an almost isolated disorder of voluntary micturition.

Chapter III.—Résumé of the Experimental Results of Studies on the Innervation of the Bladder and Urethra.

In the study of all complex nervous problems the point of view and mode of approach laid down by the great masters, who have unravelled so much of the physiology and made clear so much regarding the functions of the nervous system, should be kept before our minds constantly. Hughlings Jackson first emphasized the necessity for

studying all the effects, both positive and negative, of damage or removal of controlling "levels" of the nervous system. Gaskell restored the hierarchy of the nervous system and showed that morphological considerations usually give the surest clue to an understanding of the present functions of the nervous system. Sherrington has shown how the nervous system is constructed so that the organism may react as a whole to changes in its external environment and so proved that the chief function of the nervous system is an integrating one. Every effector organ, before it can carry out its functions "normally" and to best advantage, must always be receiving "balanced" nervous impulses. The removal of the impulses carried by any one of the tracts which play upon the "final common path" or upon the effector organ itself leads to an unnatural state of that effector organ, and this unnatural, quasi-pathological state may be the subject of physiological investigation and clinical study. The laboratory worker possesses the advantage over the clinician that, if he has not completed his observations or is doubtful upon certain points, he can repeat the circumstances which he desires to study, whilst the clinician must wait until disease or injury, over which he has little or no control, provide him with another opportunity favourable for investigations. Moreover, the experimenter can make his interferences with conducting parts minimal or maximal at will, and can also graduate his stimuli. Between the activities of the bladder freed experimentally, in part or completely, from its central nervous connections and the bladder working under normal natural conditions, certain features only are common, and authors who have attempted to translate the activities of this organ from the one state into the other have often gone wildly astray in their deductions.

The bladder in the various groups of mammals shows wide variations in the thickness of its muscular wall, in its relative size and capacity as compared with the rest of the body, and in the frequency with which normally its contents are discharged. These variations, according to Elliott [11], are associated with similar variations in its innervation. They are teleological and are not determined by ties of zoological kinship, so that deductions drawn from experimental study of a single type cannot be applied universally. "To determine the nervous control of the bladder with its simple structure and single function, might seem no hard task," wrote Elliott in 1906, "yet some of the main facts are still disputed." This author, for his principal study, took the cat; he then compared his findings in the cat with the

observations which he made upon the dog, the rabbit, the ferret, the monkey (*Macacus rhesus*), the mongoose, the Indian civet cat, the pig and the goat and with the few certain records of investigations upon the bladder of man. The results of this author and other observers may be summarized as follows :—

(1) *Effects upon the Ureters, Bladder and Urethra of Stimulation of the Nerves passing to the Bladder, &c.*

(*a*) *The pelvic nerves* (*nervi erigentes*).—In all the mammals which have been studied so far it has been proved that brief excitation, immediately after section, of the peripheral ends of one or other of the two pelvic nerves or of the sacral anterior roots, which send fibres to join the pelvic nerves and thus supply the pelvic viscera, causes a contraction of the bladder followed immediately by a relaxation. In some of the animals investigated such excitation also leads to an inhibition of the sphincter muscle at the neck of the bladder and of the unstriped muscle surrounding the urethra with consequent dilatation of the urethral canal. In the cat, Langley [29] has shown that if the effective nerves be stimulated for 20 to 30 seconds the contraction evoked leads to complete evacuation of the contents of a bladder containing 50 to 80 c.c., and that the longer the stimulus has lasted the slower the relaxation after it has ceased. In experiments in which the stimulation lasted still longer Langley found that contraction did not always persist throughout the period of stimulation, though this was not a constant finding. The rate of relaxation is also dependent upon the pressure to which the contents are subjected during the period of stimulation. Post-ganglionic stimulation of branches from the pelvic nerves gives a contraction which does not differ in any definite way from that produced by pre-ganglionic stimulation.

From the effects of peripheral stimulation of the pelvic visceral nerves it is now certain that these are the vesical nerves concerned with micturition (Von Zeissl [65], Elliott [11]).

(*b*) *The hypogastric nerves.*—Concerning the motor activities of the hypogastric nerves first described by Sokownin, in 1874, the observations of different experimenters[1] have always shown a considerable

[1] Sokownin [56], Nussbaum [45], Nawrocki and Skabitschewsky [43, 44], Sherrington (50], Langley and Anderson, Stewart [58], working on the cat, and von Zeissl, Griffiths [19], Hanc [21], Rehfisch [47], Fagge [12], Wlasow [61] on the dog, Budge [3, 4], Nawrocki and Skabitschewsky [43, 44], Langley and Anderson on the rabbit, Sherrington [51] on the monkey.

agreement with regard to excitation of the peripheral ends of the previously divided nerves in any one animal. But until the appearance of Elliott's [11] work in 1906 the great discrepancies between the results obtained in the various animals, more especially between the effects described as occurring in the cat and in the dog, had not been understood. Elliott describes three types of effect upon the bladder resulting from stimulation of the hypogastric nerves:—

Type I.—In the ferret stimulation leads to a constriction of the whole urethra and the whole of the surface of the bladder. In the male goat a similar but slighter contraction of the whole bladder was elicited.

Type II.—In the cat stimulation of the hypogastric nerves causes a constriction without shortening of the whole of the urethra and at the same time a relaxation of the rest of the bladder. In the pig and monkey a similar but less extensive inhibition of the bladder occurs on stimulation of the hypogastric nerves.

Type III.—In the dog hypogastric stimulation causes contraction of the urethra and of a very small area at the back of the base of the bladder only; neither synchronous and universal inhibition, nor contraction of the whole bladder occurs under these conditions. The bladder in the rabbit, in the female goat and in the mongoose behaves like that of the dog, in so far as stimulation of the hypogastric nerves causes a contraction of a narrow area at the base only. Observations, so far as they go at present, tend to show that in man the hypogastric nerves cannot inhibit the bladder to any great extent.

Thus in all the mammals upon which experiments have been recorded, excitation of the hypogastric nerves produces a constriction of the unstriped muscle of the urethra and a contraction of the muscle at the base of the bladder *with* or *without* a concomitant contraction or relaxation of the rest of the bladder. Elliott [11], and Gaskell [16], suggest that these differences are to be sought in the ontogenetic sources of the musculature: "In the ferret, perhaps, the muscle innervated by the hypogastrics is a sheet separate from that innervated by the pelvics, being an upward extension from the area between the ureters where contraction is observed in all mammals; its functional use was not ascertained" (Elliott [11], p. 444).

Stimulation of the sympathetic nerves on the application of adrenalin did not produce in any animal constriction of the ureter or much constriction of the blood-vessels of the bladder, although anatomically, as shown by the dissections of Langley and Anderson, the ureters are supplied with branches from the sympathetic nerves [34].

The axon-reflex through the inferior mesenteric ganglia.—Sokownin [56], in 1874, showed in the cat that when the nervous connexions of the inferior mesenteric ganglia with the exception of the hypogastric nerves are severed, and then one hypogastric nerve is cut and its *central* end stimulated electrically, contraction of the base of the bladder is produced on the contralateral side. Sokownin interpreted this result as a "reflex-action" through the peripherally placed sympathetic ganglia. Langley and Anderson [30] investigated this "reflex" in 1894, and showed that the contraction at the base of the bladder was accompanied by contraction of the internal sphincter muscle of the anus, and by vaso-constriction of the vessels of the rectum and at times also of those of the internal generative organs. They further showed that nerve-cells took part in reflex, for the effect was destroyed by the injection of nicotine. By the method of degeneration they proved that the hypogastric fibres upon which the reflex depends had their nutritive centres in the central nervous system, for when the lumbar (inferior) splanchics were cut on the one side and time allowed for their degeneration, the Sokownin reflex was no longer possible. They concluded that the Sokownin reflex is not a reflex in the ordinary sense of the word, but action brought about through branchings of the pre-ganglionic connector fibres of the lumbar splanchnic nerves. No special afferent nerve-fibre or cell takes any part in this reflex. Many of the efferent pre-ganglionic fibres branch repeatedly, and for the purpose of this reflex one branch running to a nerve-cell supplying one side of the bladder, and another to a nerve-cell supplying the other side of the bladder, suffices. In 1900, Langley [25] returned to the study of this subject of "axon-reflexes" in the pre-ganglionic fibres of the sympathetic system and found exactly similar phenomena in ganglia of the lateral chain, and thus brought forward evidence to prove the truth of the view that the connector nerve-fibres of the involuntary nervous system behave like those of the voluntary nervous system, and give off collaterals to a number of ganglion cells; in consequence of such collaterals an "axon-reflex" can be elicited in organs entirely separated from the central nervous system. In 1906 Elliott showed that by means of an "axon-reflex" not only contraction, but also, less readily, inhibition could be produced, and concluded that "there is no distinction between motor and inhibitor nerves in the hypogastric nerves beyond that of their final area of distribution" ([11], p. 376).

From the effects of stimulation of the nerve-fibres associated with

the sympathetic and sacral outflows of the autonomic nervous system passing to the bladder, it is seen that each nerve-trunk is " a functional unit, bearing in one bundle the nerve-fibres, motor and inhibitor, which excite at the appropriate points of the sheet of plain muscle contraction and inhibition in harmonious co-operation for a single function—a nervous co-ordination at the periphery, which is, in a manner, comparable with Sherrington's [53] central reflexes of simultaneous double sign." " In the cat the pelvic nerves to the bladder cause contraction

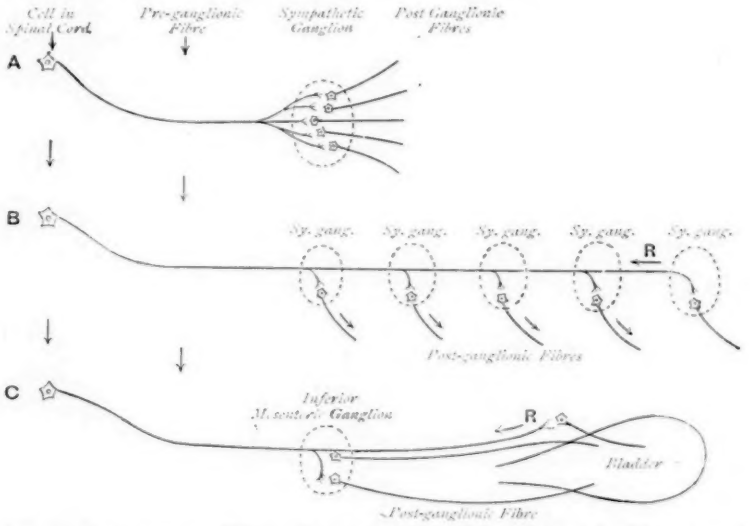


FIG. 5.—Taken from Langley in Schäfer's " Text-book of Physiology " [26] to show the mechanism of the so-called " axon reflex." **B** and **C** show the probable mechanism of these pseudo-reflexes: **B**, uncrossed, from the sympathetic chain; **C**, crossed, from the hypogastric nerves. With the arrangement given in **A** (some compound ganglia) pseudo-reflexes are not obtained.

of the entire bladder and relaxation of the urethra, movements adapted for the discharge of urine. On the other side the hypogastric nerves facilitate retention of urine by constricting the urethra, that is the sphincter of the bladder, and inhibiting the tone of the detrusor urinæ. From the point of view of function the two nerve trunks are completely antagonistic to one another ($P\pm$ and $H\mp$). In other animals the peripheral machinery for expulsion of urine is generally the same ($P\pm$), but that for retention is less highly developed and effects merely closure of the sphincter ($H+$). None the less the functional antagonism holds. So the simple and obvious rule that connects the visceral movements

and gives order to their apparent complexity is this of teleological adaptation; the functional development of nervous ties between the central nervous system and a muscular tissue depends on the daily need" (Elliott [11], pp. 403-5). Moreover, "the development of these ties (with the various nerves), whether it shall be called 'trophic,' or be made the instrument of motor or inhibitor nervous impulses, is governed by the requirements of the individual organ and must be studied in each particular case" (Elliott [11], p. 411).

(*c*) *The pudic nerves.*—Electrical stimulation of the peripheral ends of the divided pudic nerves causes a contraction of the voluntary striped muscle surrounding the urethra. This contraction becomes rapidly fatigued, and unlike the contractions produced by stimulation of the pelvic or hypogastric nerves, is completely abolished by the drug curare (Barrington [1]).

(2) *Effects upon the Bladder and Urethra of Degenerative Section of the Various Nerves, &c.*

Elliott was the first author to demonstrate the tonic action of the central nervous system upon the bladder; this action has been investigated by examining the bladder both immediately after section of the various nerves and also at varying dates subsequent to the division.

(*a*) *The inferior splanchnics.*—Pre-ganglionic section of the inhibitor nerves to the bladder, carried out by dividing the inferior splanchnic nerves on both sides of the body, and thus causing an isolation from the central nervous system of the neurons constituting the hypogastric nerves, in the cat, leads to an immediate and a permanent rise in the tone of the bladder, but does not affect micturition. The muscle in this state of heightened tone was found to have lost its supple readiness to nervous control either in the direction of contraction or relaxation (Elliott [11]).

(*b*) *The hypogastric nerves.*—Degenerative section of these nerves removes most of the post-ganglionic inhibitor nerves of the bladder and also most of those nerve-fibres which carry the efferent impulses causing constriction of the unstriped muscle of the urethra. It does not make a dog or cat unable to retain urine, nor does it grossly affect either the frequency or the character of the act of micturition (Mosso and Pellacani [41], Elliott [11]), nor does it render the bladder and urethra insensible to stimulation by adrenalin. In the cat, after degeneration has had time to appear, the capacity of the bladder falls, its muscle fibres become less supple, and much of its automatic rhythm

is lost, i.e., under such circumstances the muscle assumes properties similar to those exhibited in animals whose bladders never possessed inhibitor nerves, e.g., the dog and man (Elliott [11]), and yet each act of micturition discharges the total contents of the bladder.

(*c*) *One pelvic nerve.* Preganglionic section of one pelvic nerve causes the decentralized half of the bladder to relax greatly, but such atonic paralysis soon disappears. During the stage of relaxation the inhibitory action of the hypogastric nerve in the cat is greatly increased, possibly owing to the excessive, unbalanced activity of the "centres" in the spinal cord. Stimulation of the undivided pelvic nerve on the ninth day after section was found by Elliott to give rise to an almost purely ipsilateral contraction, but within three weeks the contraction on stimulation of the surviving contralateral nerve was bilateral and symmetrical, and the tone of the whole bladder wall was heightened as compared with that of the normal bladder. Elliott explains these latter observations as due to the budding out of peripheral neurons and their fibres and the development of an "axon-reflex."

(*d*) *Both pelvic nerves.*—Degenerative section of both pelvic nerves in the otherwise intact animal removes all the preganglionic sacral motor nerves, and at the same time removes nearly all the sensory fibres from the bladder. In the cat, (Elliott [11]), and in the dog (Lannegrace [35]), this operation leads for a time to the disappearance of all the rhythmical movements of the bladder and to complete paralysis of micturition, so that the bladder must be emptied by external pressure upon the abdomen. For a few days after the operation this emptying process meets with great resistance. This resistance seems to be due to a deliberate closure of the urethra through the activities of the hypogastric nerves, but later these activities seem to diminish, for the evacuation is then performed with great facility. At this early stage, if the distension of the bladder be not relieved artificially, hæmorrhages into the mucous membrane of the bladder with subsequent ulceration and hæmaturia develop. Four or five weeks after the operation the bladder develops the power of spontaneously discharging some of its contents unknown to the animal. The distension itself does not appear to set up painful impulses, though the animal is apparently conscious of the need for urination, for it has been noticed to seek time and place suitable for that act. The power of spontaneously discharging the contents of the bladder increases regularly day by day after its first inception, and from the sixth week onward there is never need of further attention to the bladder of the cat. After the recovery from such degenerative

section of both pelvic nerves, however, the stream of urine in micturition is always feeble and only a portion of the contents of the bladder, whose total capacity is permanently diminished, is discharged at any one micturition, a considerable quantity of urine always remaining in the bladder. Moreover, the total quantity passed does not come away in any single act of micturition, the bladder "stammers," and any active movement on the part of the animal leads to the passage of a small quantity of urine. After degenerative section of the pelvic nerves stimulation of the hypogastric nerves by electricity or by adrenalin produces a quick and ready inhibition upon the bladder if its condition and that of the animal be good and the bladder still shows rhythmic movements.

(*e*) *Both pudic nerves.*—Section of these two nerves constantly produces some degree of incontinence of urine, but the severity of this incontinence varies considerably; it is never compensated by over-activity along other efferent channels. The incontinence is unaffected by subsequent removal of the hypogastric nerves (Barrington [1]).

(*f*) *Both pelvic nerves and both hypogastric nerves.*—In dogs, von Zeissl [62-66], Lewandowsky and Schulz [36], and Wlasow [61] showed that after section of these four nerves the bladder eventually develops the power of discharging a hundred or more cubic centimetres of urine at a time and in Elliott's experiments on cats, in which all four nerves were divided, micturition was restored, just as after division of the pelvic nerves alone, in the fourth or fifth week. Moreover, Elliott was able to show that the spontaneous periodic discharge of urine which reappears some four to five weeks after the section of both pelvic nerves is *not* affected by a further division of the hypogastric nerves; nor is it affected, as Barrington's experiments show, by excision of the inferior mesenteric ganglia. Thus it is certain "that the spontaneous discharge of urine, when ultimately established after degenerative section of the pelvic nerves, is a local act which is entirely independent of the nerves which unite the organ with the central nervous system" (Elliott [11], p. 428).

(*g*) *Both pelvic nerves and both pudic nerves.*—Barrington [1] found that after section of these four nerves both the resistance of the urethra and the bladder capacity became minimal, so that urine constantly dribbled away whenever pressure was exerted upon the bladder. The integrity of the pudics is necessary both for the urethral tone and its relaxation when the contents of the bladder are artificially expressed; they are also necessary for the sensation which makes the cat with divided pelvic nerves conscious of the fact that it wants to pass water.

By experiment it has been shown further that urethral tone and this sensation are independent of hypogastric innervation.

(*h*) *All the sacral posterior* (*dorsal*) *roots.*—Merzbacher [40] and Barrington [1] have shown that permanent retention of urine always

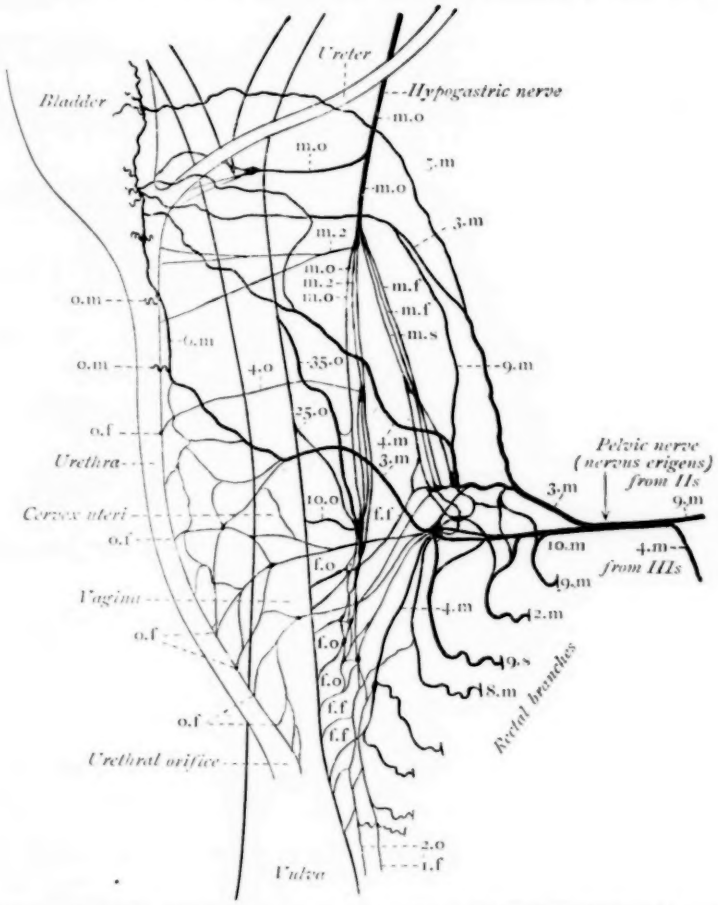


FIG. 6.—From Langley and Anderson [33] (p. 374). Left pelvic plexus of cat. The three sacral nerves and the first coccygeal nerve were cut peripherally of the spinal ganglia, and eleven days allowed for degeneration. The numbers placed opposite each strand show the number of normal and of degenerated fibres present in it—the number of normal fibres being placed first. Thus 35·0 indicates that the strand contained thirty-five normal fibres and not one degenerated: m signifies many fibres (more than twenty-five); s signifies some (ten to twenty five); and f, a few fibres (nine or less). Thus 9·m signifies that nine sound and more than twenty-five degenerated fibres were present in the strand.

develops after the operation of division of all the sacral posterior roots. This retention of urine is accompanied by a laxity (postural hypotonus), which allows gross over-distension of the bladder, a state of which the cat is quite oblivious. Left to itself the over-distended bladder allows a few drops of urine to dribble away at irregular but frequent intervals, but never evacuates any considerable quantity of urine. The degree of laxity has been found to be greater after division of the sacral posterior roots than it is either after section of both pelvic nerves or after transection of the spinal cord.

(*i*) *All the lumbar roots (anterior and posterior).*—Sherrington [51] in 1894 reported as the results of dividing all the lumbar roots in the cat a paralysis of the bladder which was completely recovered from in twenty-four hours.

(*j*) *Transection of the spinal cord.*—Upon the bladder and upon micturition the immediate effects of a transection of the spinal cord above the level of the origin of the upper sacral roots in the cat, in the dog, in the rabbit and in the monkey are strikingly similar to those produced by section of both pelvic nerves. For a certain period after operation complete retention of urine develops, accompanied by a lax condition of the bladder which allows great over-distension of the organ, and also by a considerable degree of spasm at the neck of the bladder and of the urethra, so that to the passage of a catheter or to abdominal manipulation a considerable resistance at the proximal end of the urethra is presented. If the retention at this stage after operation be not relieved, urine begins to leak away from the over-distended bladder and escapes from the urethra drop by drop. Abdominal manipulation at this stage leads to the escape of a small jet of urine only; after the evacuation of a small quantity of urine the bladder wall does not contract down upon its contents, with the consequence that total evacuation of the accumulated urine even with repeated manipulations is almost impossible. The stimulation of the nerves passing to the sacral cord, moreover, does not lead to the emptying of the bladder. If during this stage the over-distension of the bladder be not relieved, hæmaturia may result.

No noteworthy differences in the degree of this primary depression of the activities of the bladder have been observed either in the cat, rabbit or monkey, dependent upon the exact level of the transection, provided that it lies between the sixth cervical above, where take origin the nerves to the diaphragm, and the fourth lumbar below: although with transection at the lower levels the hypogastric afferent and efferent

paths are both destroyed. Moreover, the immediate depression seems as severe in the rabbit and in the cat as in the monkey (Sherrington [52]).

Within a few days after operation, the exact time depending apparently upon (1) the level of the transection; (2) the species of animal; and (3) the general physical condition of the animal, the laxity of the bladder and the resistance at its neck are both found to diminish. Associated with this increase in tone of the bladder wall, it is now found easy to empty the bladder of the cat by abdominal manipulation, for after the passage of a certain quantity of urine the bladder musculature contracts down upon the vesical contents. Within a few days after the appearance of this stage the animal is seen to void urine spontaneously in small rhythmic jets, the frequency and also the quantity of urine so voided increasing steadily from day to day if the general condition of the animal be good. Although this type of passage of urine may occur "spontaneously" at this stage, it can more readily be provoked reflexly, e.g., by sponging or scratching the perineal region, or by holding the animal up in such a way that gravity stimulates the hind limbs, when evacuation is usually associated with movements of the tail, contraction of the perineal muscles and even with clonic movements of the paralysed hinder limbs or with defæcation. By reflex stimulation a series of jets of urine can be obtained, but the passage of urine in this manner always stops short before the bladder is completely emptied; a certain quantity of residual urine always remains in the bladder at a time when no further reflex passage can be elicited. The quantity of residual urine varies with the species of animals and in cats has been shown to vary greatly with the individual, but in any single individual to be fairly constant. Moreover, the amount of residual urine after which no further voidance of urine can be elicited varies with the point selected for reflex stimulation. Barrington [1] found that in cats, in which the amount of residual urine is large, the urine begins to be passed spontaneously before the maximal amount of residual urine is attained. Moreover, just as Elliott found after division of both pelvic nerves, the bladders of the cats examined in this stage were considerably thickened. In the dog the stage of "spontaneous" periodic reflex micturition often develops very early after spinal transection.

It is noteworthy that though in association with over-distension hæmaturia be allowed to develop in experimental animals, as soon as the over-distension has ceased the urine has but rarely been found to contain pus cells, and Sherrington [52] with his large experience in this

class of case wrote in 1900: "I have never seen cystitis ensue after spinal transection in laboratory animals, although the animals have been kept under observation many months."

(k) Excision of the lower part of the spinal cord.—Goltz and Ewald [18] in 1896 excised the whole of the spinal cord below the upper thoracic region in the dog and found that in this animal a stage of retention of urine accompanied by a state of overdistension of the bladder lasting for a considerable number of days resulted, but that this stage was followed by a stage of "spontaneous" periodic micturition, closely simulating the spontaneous micturition which develops after transection of the spinal cord or after division of both pelvic nerves.[1] Müller [42] in 1901 made similar experiments upon dogs but with less extensive removals of the spinal cord, and confirmed the results of Goltz and Ewald. Müller found no differences depending upon the level of the lesion between the times at which this spontaneous micturition developed, but noted that after excision of the lower portion of the spinal cord stimulation of the hinder regions of the animal no reflex discharge of urine could be produced such as occurs at the similar stage after a simple transection of the spinal cord. He writes: "Nach einige Wochen kommt es zu spontanen, ausgiebigen Entleerungen der Blase. Solche sind nach einfacher Durchschneidung des Rückenmarks stets auch reflectorisch durch Hautreize am Hinterkörper auszulösen, was bei Thieren, denen der untere Theil des Rückenmarks herausgenommen wurde, niemals möglich ist. Insbesondere bein Hündinnen erzeugt schon das Berühren der Genitalien oder Kneifen des Schwanzes stets stossweise Harnentleerung. Nach Durchtrennung des Marks zwischen der Lendenanschwellung und dem Brustmark sind bei den Thieren die Reflexe an den für den Willensimpuls gelähmten hinteren Extremitäten ungemein lebhaft und vielseitig (Zappel- und Gehreflexe). Die sensiblen Reize lösen aber nicht nur Bewegungen in der quergestreiften Musculatur der hinteren Extremitäten aus, sondern sie führen auch zu Contractionen von Organen mit glatter Musculatur." Spontaneous micturition when it develops is unconscious and involuntary, but can be started by fright. Examination of the bladder at this stage showed that the muscular wall was greatly thickened.

After decentralization of the bladder, whether by section of all the peripheral nerves, by excision of the lumbo-sacral spinal cord, or by low transection of the spinal cord, as soon as the bladder has taken on

[1] It is noteworthy that in several of Goltz and Ewald's dogs cystitis developed, but these animals were subjected to catheterization.

periodic " spontaneous micturition " a curious state of torpid overgrowth of the musculature of the bladder wall has been found to result. This overgrowth in cats was found by Elliott [11] (p. 430), to be associated histologically with both a multiplication in the number of unstriped muscular fibres, and also with a cross-sectional increase in each single fibre, and physiologically with a deterioration in suppleness and irritability to electrical stimulation of the muscle itself.

(*l*) *Denervated muscle.*—In the cat Elliott [11] attempted to denervate the vesical musculature completely by dissecting away all the post-ganglionic branches of the hypogastric nerves and all the pre-ganglionic pelvic fibres, and picking the ganglia associated with the pelvic nerves off from the *surface* of the bladder (very few lie deeply below the surface). By this operation he was able to obtain a bladder which except for a few afferent sensory fibres was totally denervated. " The operation did not interfere with micturition." He found that the muscle denervated in this manner showed no rhythmical movements, had only dull irritability to electrical stimulation, but that its vascular supply was little affected. The denervated muscle of the bladder thus contrasts strongly with decentralized plain muscle of the bladder, which, before entering on the period of torpid overgrowth (cf. section (*k*) above), is supple and quick to respond in all its area to electrical stimulation and also exhibits rhythmical movements. Thus it is seen that the quick contraction of one half of the bladder which results from direct faradization of the normal bladder wall is effected by the stimulus spreading in the nerves, and not by conduction in the plexus of plain muscle.

Chapter IV.—General Physiology of the Innervation of the Bladder and Urethra.

According to modern conceptions concerning the activities of muscle and nerve, in the higher vertebrates every contractile tissue during the whole course of its physiological life, whether made up of striped or unstriped elements, is in the constant receipt of impulses from the central nervous system through its effector, motor nerves; and similarly from every contractile tissue afferent impulses are constantly streaming centralwards. The activities of the contractile tissue are thus always controlled, and the actual state of the tissue at any single instant is the resultant of a " balance." The influence of the central nervous system upon the contractile tissue is spoken of as being " tonic "

and the resulting relations of the part or organ relative to the body as a whole are spoken of as being "postural." Posture so defined is in the majority of instances an active response on the part of an "integrating" nervous system to the forces tending to disturb the configuration of the part; while the state of the muscle, so long as the posture holds, is such as to prevent movement and is "static." A hollow muscular organ, such as the bladder, after partial evacuation, or after addition to its contents, assumes under the influence of the nervous system a new configuration conformably with this changed volume, and this new configuration is maintained statically. Every stimulus which passes into the central nervous system tends to affect to a greater or less degree the static configuration which is thus maintained reflexly, but the stimuli reaching the central nervous system from the actively contracting elements themselves seem to be the most important factors both in keeping the balance unchanged and in changing the balance itself. Amongst the contractile tissues the dynamic activities which result in the production of movement are reactions equally definitely balanced to the incoming streams of nervous stimuli. Dynamic activities can only proceed regularly and naturally if the "static" tone of the organ or part be normal; thus for an understanding of the problems of the functional activities of the bladder a study of the "static" or "postural" states is as necessary as a study of the modes of its evacuation during micturition; and yet until recent years the study of the dynamic activities of the bladder and other organs has alone dominated the thoughts of investigators. Thus after transection of the spinal cord or degenerative section of both pelvic nerves, although the bladder periodically discharges some of its contents spontaneously, authors who have assumed that this was a form of "normal micturition" have misinterpreted many points in the physiology of this organ. For after such an evacuation the bladder is often not completely emptied and the quantity of urine which the bladder contains at the moment of spontaneous discharge in any single animal is very variable. In man during the course of diseases affecting, or after injury to, the nervous mechanisms controlling the lower urinary tract, the destruction of nervous tissues produces both pure loss of ability to perform certain activities, and also leads to certain positive effects due to the released activities of undamaged portions of the nervous system. In order that a bladder may evacuate its contents normally and at the appointed times all the paths from and to the central nervous system must be intact; and yet there is no doubt that

the fully decentralized bladder is capable of automatic, if feeble, contraction and discharge of urine.

The original experiments conducted in the laboratory have led on the anatomical side to enormous advances in our knowledge of the nervous mechanisms which exercise a control upon the bladder, and have revealed, on the physiological side, much concerning the forms of activity which can be set up by sending abnormally large, transient, nervous impulses along the various efferent channels. Thus it has been shown that the hypogastric nerves in all mammals send impulses to the bladder which are reciprocally antagonistic to those conducted by the pelvic nerves and vice versâ. Injury and disease in man are accompanied in but a limited number of cases by this excessive discharge of nervous energy; more usually our patients exhibit, over prolonged periods, a diminution in the number and size of the impulses carried, and thus this knowledge gained in the laboratory has not resulted in much of practical advantage to the clinician. Moreover, the connecting paths outside the spinal canal have been chiefly studied experimentally, for they are easier of approach than the central mechanisms, which are affected in the great majority of the patients with "nervous bladder trouble," who need the care of the surgeon or physician. Thus it happened that until the appearance of the work of Elliott [11] and Sherrington [55], which has shown the tonic influence of the central nervous control that is constantly being exercised upon the bladder, clinical interest was not awakened in the fascinating physiological problems exhibited by the bladder. The differences in point of view between the laboratory worker and the clinician are well illustrated by the Sokownin-reflex. The elucidation of the mechanism of this axon-reflex in the hands of Langley and Anderson [30], of Langley [25] and of Elliott [11], has yielded much purely anatomical information concerning the minute anatomy and mingling interconnections of the connector fibres of the pre-ganglionic neurons of the sympathetic nervous outflow and held the attention of physiologists; but on the other hand, being merely an aberrant, experimental possibility which in all probability is a very infrequent and unnatural mode of conduction in the intact animal, has excited little interest in workers at the bedside. The observations upon the disturbances of the vesical activities which result after transection of the spinal cord in animals, or after degenerative section of the pelvic nerves, have interested greatly all workers who have had to deal with cases of gunshot wounds of the spine. For in cases of injury to the spine and in patients suffering

from chronic diseases of the lower half of the spinal cord the state of the bladder is the most important factor in the prognosis *ad vitam* of the patient. The configuration of the bladder at the end of micturition is a fundamental factor in the infections of the urinary tract. A quantity of urine (residual urine) remaining in the bladder after spontaneous or voluntary evacuation of the bladder forms a nidus suitable for the growth of micro-organisms; moreover, the bladder is a cavity which, though contained inside the somatic walls, acts, like the alimentary canal, as an external portion of the body in so far as it is out of the range of medicaments coursing in the blood-stream.

Mosso and Pellacani [41] were the first to publish, in 1882, a series of observations upon the urinary bladder proving that this organ could not be regarded as a simple elastic bladder capable of emptying itself when under the accumulation of its contents it became "full." They showed by experiments upon man and dogs that even when the bladder in the intact animal is emptied as completely as possible the pressure upon the contents is always a definitely measurable quantity and never zero. Moreover, under one and the same pressure observations upon the vesical contents at short intervals showed different volumes. They concluded that in a normal man an intravesical pressure of 18 cm. of water is usually accompanied by a desire to micturate, and they pointed out that the stimulus exciting desire to micturate is closely related to intravesical pressure, but is not closely related to the quantity of vesical contents. They found that the sense of fulness in the bladder arises in the same person according to circumstances with varying volumes of the bladder contents. After the development of this sensation the feeling disappeared in a few minutes if micturition were prevented. Moreover, they found that the viscus responded to an increment in volume by a sort of active diastole proportional to the volume of increment, and to a diminution in volume by an active systole similarly proportioned, and that when fluid was artificially supplied to the urinary bladder a fluid pressure of nearly the same amount as before was re-established. The living bladder, unlike the dead bladder or rubber bag, enfolds its contents with the same light grip whether these contents be large or small. In Sherrington's words, "the bladder assumes postures suited to the volume of its contents."

Reflex postural contraction, both in skeletal and in visceral muscle, is characterized by (1) the low degree of tension it usually develops; (2) the long periods for which it is very commonly maintained; (3) the difficulty in obtaining by artificial—e.g., electrical—stimulation reflex

contraction at all simulating the postural contraction produced by the natural stimuli, whatever these may be; (4) by the relative ease with which reflex inhibition interrupts the postural contraction; and by (5) the "lengthening" and (6) the "shortening" reactions obtainable from muscles exhibiting postural contraction. Reflex maintenance and adjustment of posture is a chief portion of the reflex work of the proprioceptive portions of the nervous system, just as sensation and perception of posture is a chief portion of the psychical output of that system (Sherrington [55]).

By experiment Elliott [11] and Barrington [1] have shown that during life a tonic action is constantly being exercised upon the bladder. In the cat after section of both pelvic nerves the bladder becomes more capacious than normal, and ceases to show rhythmic movements, whilst after section of the lumbar splanchnic or hypogastric nerves, whether the pelvic nerves are divided or intact, the capacity of the bladder falls, and its muscular fibres show a persistent contraction, which is maximal immediately after section of the preganglionic nerve-fibres of the sympathetic outflow. In experiments the degree of this contraction was found to be dependent upon the depth of anæsthesia and the general state of the animal obtaining at the time of section. Further, the measure of this tonic contraction is greater when the connections of the hypogastric nerves with the inferior mesenteric ganglia are not interfered with than if the section be made in the course of the post-ganglionic fibres. After transection of the spinal cord, a contraction of the muscle of the bladder lasting for a short period, followed by a relaxation lasting for a considerable but variable time, occurs. The relaxation so obtained is not dependent upon the blood-pressure, and is brought about through some portion of the nervous system lying headward of the mid-thoracic region of the spinal cord. From his own experiments Barrington was led to conclude that the inhibitor effect upon the bladder is exercised from (1) the mid-thoracic region of the spinal cord; (2) the region of the spinal cord from which the lumbar splanchnic fibres arise; (3) the inferior mesenteric ganglia; in decreasing amounts, whilst the whole of the pressor, motor-tone would seem to leave the spinal cord by the pelvic nerves, and to originate in the central nervous system of the cat in parts lying at least as high as the mid-thoracic region. Investigations of the tonic influence of the nervous system on the urethra show that the pudic and pelvic nerves exercise upon the urethra an opposing influence, motor and inhibitor respectively, which is independent of the integrity

of the thoracic spinal cord, but dependent upon the activity of the lumbo-sacral cord. Barrington was unable to find any evidence that motor-tone is exercised upon the urethra through the hypogastric nerves. The tonic action upon the urethra is thus "local," and does not descend from anywhere above the parts of the spinal cord, which give origin to its nerves of supply. In this last point the urethra differs essentially from the bladder.

Micturition.—In the anæsthetized cat or dog reflex evacuation is easily produced by the over-distension of the bladder. The reflex is not affected by section of the hypogastric nerves, but disappears when the two pelvic nerves are severed or the lower thoracic cord is divided; it is greatly depressed or completely abolished when the central nervous system is under the influence of "shock," for example, it is usually abolished by the act of destroying the brain. Stewart [58] attempted to determine the upper limit of the reflex "centre" in the spinal cord of the cat by a method of successive transections. The sciatic nerves were severed, and the reflex effects of stimulation of the central end of this nerve upon the bladder observed after sections across the spinal cord had been made at various levels. This author found that even during the first twenty-four hours after operation a reflex contraction of the bladder could be readily elicited if the spinal transection had been made headward of the origin of the second lumbar root. Barrington, as the result of his experiments, was led to doubt whether this contraction bears any direct relation with the reflex of micturition, because (1) under such circumstances, though contraction was the more common effect, dilatation often occurred; (2) the contractions when obtained were always slight, and quite unlike those produced by stimulation of one pelvic nerve; (3) the contraction obtained was transient, and never maintained to the end of the stimulus; and (4) if in addition to a transection of the cord one pelvic nerve were severed, and then the effects of central stimulation of the pelvic, the pudic, the sciatic, and of a branch of the anterior crural nerves on the other half of the body were systematically investigated, the nerves entering the cord nearest the origin of the remaining pelvic gave the greatest, and those farthest away the least contraction. Barrington explains Stewart's observations as effects of strong afferent impulses producing general disturbances in the spinal cord.

Goltz in 1874 [17A] propounded a scheme, which has since been accepted by many authors, of normal micturition occurring through a conscious reflex. He supposed that distension of the bladder increases

the amplitude of the rhythmic movements until on the crest of one of these urine is forced beyond the barrier of the sphincter vesicæ into the urethra, irritates the urethral mucous membrane and leads to the development of the sensation of the necessity for evacuation ("Harndrang"). According to this scheme distension of the bladder is the primary cause of micturition and leads to contraction of the bladder, then consciousness is affected by urine escaping into the urethra, and as a secondary result either deliberate facilitation of discharge is evoked by voluntary contraction of the muscles of the abdominal wall, or micturition is deliberately repressed by a willed contraction of the sphincter muscles of the urethra. Goltz's view was later misinterpreted and the whole of the reflex came to be regarded by some writers as having a purely urethral origin; this view is absolutely disproved by the fact that urination can still be started when the urethra is completely occluded by a catheter and is rendered improbable by the observation that micturition is little affected when the mucous membrane of the posterior urethra is completely destroyed by diseases such as chronic gonorrhœa, or by the operation of suprapubic prostatectomy. The reflex is certainly largely determined by the tension exerted upon the intravesical contents (Mosso [41], von Zeissl [64, 65], Guyon [20]), and depends upon the integrity of the afferent vesical fibres carried by the pelvic nerves, but may be influenced from many other points. It may be started by stimulation of remote parts, e.g., in a cat which has suckled kittens by stimulation of the nipple (Elliott [11]), or by cutaneous stimulation of the perineum or lower extremities; and we know as the result of experiments that stimulation of any sensory peripheral nerve produces a greater or less increase in the tension exerted upon the intravesical contents.

The main events in reflex micturition may be summarized as follows: (1) Accumulation of urine; (2) slow rise of intravesical pressure to 15 to 18 cm. of water; (3) rhythmical contractions of the bladder, increasing in force with increasing tension; (4) afferent impulses ascending from the bladder chiefly by the pelvic nerves to the lumbo-sacral cord and higher parts of the central nervous system; (5) reflex discharge of pressor impulses by the pelvic nerves to the muscle of the bladder wall and inhibitor impulses to the sphincter muscle at the neck of the bladder (probably not associated with any inhibitor impulses to the bladder carried by the hypogastric nerves) causing contraction of the whole bladder wall, and a rise of intravesical tension to 20 to 30 cm. of water; (6) the resistance at the neck of the bladder is overcome, the

first part of the urethra is straightened out, and the walls of the empty tube forced apart; (7) discharge of urine and emptying of the bladder; (8) contraction of the unstriated and striated muscles surrounding the urethra and emptying this canal owing to the arrival of impulses by the pudic nerves. At (5) there will be in nearly every case a reinforcing contraction of voluntary origin of the abdominal and respiratory muscles.

Voluntary control of micturition.—In young children micturition is an unconscious act depending purely upon reflex processes, but in the adult retention and evacuation of urine can be controlled by voluntary effort. The normal action of the sphincter mechanism can now be aided by a contraction of the striated perineal muscles which help in the closure of the urethra. In such adults two definite forms of micturition occur, "micturition on desire" and "voluntary micturition." In the latter form the act of micturition is started by a willed effort which affects the lower centres in much the same way apparently as do afferent impulses arising either from the bladder itself or more purely reflexly in sensory nerves supplying other parts of the body. The series of striated muscles which surround the urethra are under the control of the will, so that in the adult micturition, when started, can be stopped at any instant. Rehfisch [47], as the result of experiments upon man, came to the conclusion that the unstriated muscle at the neck of the bladder, which holds back the urine at the internal urethral meatus above the level of the prostate[1] must be under voluntary control, but his conclusions have never been accepted. This investigator found that if a catheter be pushed up the human urethra until its opening lies in the prostatic portion of the urethra just outside the bladder, no urine flows unless micturition be inaugurated voluntarily by the person experimented upon. Starling [57] suggested that these results of Rehfisch might be explained by a willed activity of the levator ani muscle, lifting up the prostate and the base of the bladder.

Cases of disease affecting the spinal cord in man and leading to interferences with the act of micturition well illustrate the rule laid down by Hughlings Jackson [23] that "dissolution occurs first in the most highly organized products of neural or mental activity, leaving the more lowly at liberty to express themselves freely in the resulting symptoms." Thus in order of development we find that (1) full voluntary control over micturition is lost, then (2) micturition on desire

[1] Cf. Barrington's radiograms of the bladder filled with a solution of colloidal silver which illustrate the similar holding back of urine in the cat.

fails, and finally (3) the periodic involuntary micturition reflex is abolished. In recording, therefore, interferences with micturition we have to ask ourselves and the patient: (*a*) How often must the bladder be emptied? (*b*) What quantity of urine is passed at each micturition? Is this quantity constant or variable? (*c*) Is the emptying of the bladder complete? (*d*) Is the stream powerful or feeble? (*e*) Can the stream when once initiated be stopped at will? (*f*) Do drops of urine come away after micturition has apparently ceased? (*g*) Can micturition be performed a short time after (e.g., half an hour) the last emptying of the bladder? (*h*) Can the urine be held after desire has once been felt, or must the bladder be emptied at once? (*i*) Is the passage a conscious or unconscious act? (*j*) When urine is passed involuntarily has the patient a sensation of the passage either before or during the spontaneous passage of his urine? (*k*) Is it necessary to aid the passage by pressing upon the abdomen? (*l*) Is the act of micturition a single or an interrupted sequence of events? (*m*) What is the total capacity of the bladder? (*n*) What quantity, if any, of urine remains in the bladder after evacuation has occurred?

Interferences with the power of holding the urine and the evacuation of the bladder met with clinically in disease and after injuries to the spinal cord fall into three main groups. In the first group the micturition reflex, when inaugurated, is carried out normally; in the second, the sequence of events, which normally is carried through by the micturition reflex, is not complete: whilst in the third no micturition reflex of any sort takes place.

In *Group I* two separable types of defect, representing often stages in recovery or decline of the nervous control over the bladder, occur.

(*a*) *The interferences are purely on the effector side.*—Here, whilst the patient is completely conscious of the happenings, he is unable to start, or experiences difficulty in starting, to micturate when opportunity presents, and on the other finds difficulty in holding back the stream when once desire has been felt. Moreover, under constant conditions regarding the rate of accumulation of urine in the bladder such a patient tends to require discharge at a constant volume of intravesical contents; but under the action of diuretics or after other causes of alteration in the rate of secretion on the part of the kidneys this volume may vary somewhat. Such a condition may be termed "micturition on demand."

(*b*) *The interferences are chiefly on the afferent side.*—Here a quantity of urine accumulates in the bladder, the normal reflex act of micturition takes place and urine is discharged, but the patient is

either not given the usual warning by the receipt of sensations before micturition takes place, or even throughout the whole series of events consciousness is not awakened. Such a state resembles closely the type of control of the bladder seen in young infants before education has led to an appreciation of the necessity for cleanliness in habits.

(*c*) *Interferences have occurred both on the afferent and efferent sides.*—Under such circumstances the patient is neither conscious of what is happening in the bladder, nor can he control the sequence of processes when they occur. This stage represents the complete setting free in Hughlings Jackson's sense of the lower centres. In clinical medicine the types described under (*b*) and (*c*) are usually included under the common heading of *active incontinence* or *periodic reflex micturition*.

Group II.—Local interferences with the reflexes from the bladder and urethra lead to disorders in the mechanism of micturition, of such a sort that either the bladder is not completely emptied, or the emptying takes place with a poor stream in a jerky irregular fashion and the bladder "stammers" during micturition, and "dribbles" after the main flow has ceased.

Group III.—In the third group where the reflex of micturition is abolished we may find (*a*) that there is *retention of urine* with paralysis of the bladder musculature and more especially of the detrusor mechanism accompanied by tonic activity of the sphincter muscles at the neck; this condition, if prolonged, leads to the second type of interference in this group; (*b*) *retention with dribbling overflow* or *passive incontinence*. In retention with overflow the bladder muscle relaxes and permits the accumulation of a large quantity of urine until at length the tension of the intravesical contents becomes so great that some portion of the urine, varying in amount from time to time, flows away. In such a condition the patient's bladder is never emptied completely except by artificial means, no reflex micturition of any sort takes place, but only the surplus urine beyond a certain accumulation escapes. At first in the moderately distended bladder rhythmical contractions may still occur, and such contractions are probably the cause of the expulsion of the few drops of urine which may be observed to take place every few minutes. Later, with increasing distension, the contractions cease and the overflow consists of drops of urine mechanically displaced from the bladder during somatic movements, or on the influx of fresh urine from the ureters. (*c*) In the most complete interferences with the function of the bladder *paralytic incontinence* develops. In this state there is a flaccid bladder associated with an atonic sphincter and the urine dribbles away without accumulating in the bladder.

After injuries to the spinal cord due to gunshot wounds in practically every case a stage of complete "retention of urine" commencing from the time of injury and lasting for a variable period results. During this period a lax condition of the bladder musculature as a whole, accompanied by a considerable amount of spasm at the neck of the bladder, and of the urethra, is found. As a result urine accumulates in and distends the bladder. At this stage, probably in many cases owing to spinal "shock," this distension is usually not appreciated by the patient. After a time, if the retention be not relieved artificially by means of a catheter, urine begins to leak away from the overdistended bladder. Thus at this stage the results of spinal injury in man and those seen in animals after spinal transection experiments are closely similar.

In the man the catheter is passed sooner or later after the infliction of the wound and from that time catheterization is usually continued at more or less regular intervals. Between the times of catheterization the bladder becomes distended with urine, but there is no longer any escape. Owing to the anatomical position of the bladder in man, it is not possible to relieve the distension by abdominal manipulation, with the inevitable development of infection in the urinary passages—cystitis with a more or less generalized toxic condition.

The duration of this stage of complete retention varies in different individuals, and according to Thomson Walker [60] in a series of a seventy cases the shortest was twenty-four hours, and the longest eighteen months. The average duration in thirty cases was fifty-five days, a rather longer period than has been found in experiments upon animals in which sepsis of the bladder did not develop.

To the first stage of complete "retention of urine" there succeeds, after days, weeks or months, a second stage of "periodic spontaneous micturition," or of "active reflex incontinence," which, unless much functional improvement in the spinal lesion takes place, is the permanent state of the bladder. The bladder, however, does not pass suddenly from a condition of retention with distension and dribbling overflow to one of "active reflex incontinence" in its fully developed form. But, just as in the experimental results upon animals detailed in Chapter II (p. 172), there is a transition period in which the bladder is still distended or partially distended with urine, whilst showing active contractions of its wall. By these contractions at intervals small quantities of urine are periodically expelled (periodic spontaneous micturition).

In the fully developed second stage the bladder acts apart from all voluntary control. The sphincter at its neck is active and urine accumulates in the bladder until a set capacity of the bladder is reached, then the detrusor mechanism is brought into play, the sphincter relaxes and the urine is discharged in a powerful stream. This is active reflex incontinence. It is an involuntary act. The patient is unable by any effort of will to initiate the discharge, nor can he inhibit the micturition. In the majority of cases, and in all in which the spinal injury is severe, he is also unaware when micturition is taking place.

In this stage the capacity of the bladder gradually diminishes, so that it now only holds from 2 to 10 oz. (57 to 284 c.c.), and the urine is discharged at intervals of a quarter of an hour up to two to three hours. In cases where much cystitis has developed the capacity of the bladder falls more rapidly and to a greater extent than when cystitis is mild or absent. At operations upon the bladder at this stage Thomson Walker has found that the muscular wall of the bladder is thickened and less supple than it is normally, just as Elliott has described in animals after transection of the spinal cord or after section of both the hypogastric and both the pelvic nerves.

Thomson Walker [60] sums up as the most striking points in considering the effects upon the bladder brought about by gunshot injuries to the spinal cord: Complete retention of urine occurs at the commencement in all cases of spinal injury where micturition is affected, at whatever the level (cervical, thoracic, lumbar or sacral) the injury may be, and it occurs in cauda equina lesions as well as in lesions of the spinal cord itself. Periodic reflex micturition (active incontinence) is the second phase in all lesions of the spinal cord, not excepting those involving the lumbar enlargement. Periodic reflex micturition develops in more than half the cases of "lesions of the cauda equina," but in these patients occasionally voluntary micturition follows directly on a period of complete retention.

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THE AUTOMATIC BLADDER, EXCESSIVE SWEATING AND SOME OTHER REFLEX CONDITIONS, IN GROSS INJURIES OF THE SPINAL CORD.

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THE present War has afforded innumerable opportunities for investigating the phenomena due to gross injuries of the spinal cord, and much has already been written on the clinical aspects of this subject. It was obviously impossible for any one observer to cover so vast a ground, or to add anything to the general stock of knowledge, without concentrated study of a limited portion of the field. Each one of the

writers of this paper became interested in a special group of problems working at first independently, and, as it seemed, at manifestations which had no bearing on one another. For nearly two years, Captain Riddoch had paid special attention to the phenomena which follow total transverse division of the spinal cord, more especially to the condition of the reflexes, whilst Dr. Head had set himself to discover some explanation for the excessive sweating, a well-known sequel to spinal cord injuries, of which two extreme cases had come under his notice. But as soon as we both became interested in measuring the functional capacity of the automatic bladder, we realized that we were looking at different phases of the same general problem.

The following paper is an attempt to establish certain physiological principles which have emerged from our several lines of research. We make no attempt to give a complete clinical account of the condition of the bladder, or of the various reflexes in cases of gross injury to the spinal cord, nor can we deal with the signs or symptoms of its total transverse division from the diagnostic point of view. These are treated in Riddoch's systematic study on p. 264 of the present number of this Journal. Our object in this paper is to state consecutively the physiological principles which underlie the phenomena he describes and, if possible, to give a general explanation for the remarkable behaviour of the distal end of the severed spinal cord.

We were anxious not to hamper our exposition of these principles by frequent digressions into the literature of the subject; and yet it was impossible to neglect the work of the Cambridge school of physiologists on the nature of the involuntary nervous system, which forms the basis of all our conceptions. Moreover, all the experimental work of serious importance on the innervation of the bladder has been carried out by Langley, Anderson, Elliott and other workers of this school. A combined retrospect of their results has therefore been put together by Dr. Fearnsides and precedes our paper in the present number of *Brain*. On the other hand, the literature of importance, connected with total transverse division of the spinal cord, is dealt with by Captain Riddoch in his monograph on this subject.

Our sincere thanks are due to Dr. Batten, Dr. Buzzard, Dr. Collier and Dr. Guthrie for the extreme generosity with which they have permitted us, not only to see the patients under their care, but also to publish our observations in these cases.

Chapter I.—The Automatic Bladder.

When the spinal cord has been so gravely injured that all power of voluntary micturition is abolished, urine may be voided in several different ways, depending largely on the general condition of the patient and on the treatment he has undergone.

At first there is complete retention and if no catheter is passed for several days the bladder may become over-distended and the urine pass away frequently and in small quantities; cystitis may occur in a severe form and the patient probably dies before any signs of the complete act of automatic micturition can appear. Fortunately, however, this is an uncommon event in the present day, now that the wounded are gathered in more quickly and a catheter is passed at the first Casualty Clearing Station as a matter of routine.

If cystitis has been set up and has been long continued, the bladder may shrink and its musculature be so damaged that it responds imperfectly to the tension stimuli of injected fluid; urine is passed at irregular intervals and in small quantities corresponding to the diminished vesical capacity. These, however, are not the cases with which we deal in this chapter; the patients on whom our observations were made were the fortunate ones in whom cystitis played comparatively little part and the wall of the bladder retained both its sensibility to pressure and tonic activity.

The complete act of automatic micturition, accompanied by the phenomena of spreading reflexes, may never become established, owing not only to local conditions, but to general septic poisoning. A foul bladder, pyelitis and sloughing bed-sores may produce so grave a septicæmia that the spinal cord never recovers from the primary condition of shock. It passes from the first stage into a terminal toxic degeneration without reaching a state in which it is capable of that form of widespread reflex activity that is the subject of this paper. The muscular wall may be capable of responding to fluid pressure, when a catheter is passed into the bladder, and some power of evacuation may be present under these conditions; but involuntary automatic micturition may never occur spontaneously and the patient is then dependent to the end of his life on catheterization for the passage of his urine.

If a catheter has been passed within about twenty-four hours of the injury and the urine has not been allowed subsequently to accumulate in excessive quantities, retention usually passes off, giving place first of

all to occasional and fitful evacuation. The larger quantity of urine voided in the twenty-four hours has to be withdrawn by catheter, but a small amount is passed unconsciously at irregular intervals into the bottle. After a few days in a favourable case this gives place to true automatic micturition. Some urine remains behind after each act of involuntary evacuation and this has to be removed by catheter once or twice daily. Moreover it is necessary, in most cases, that some form of wash should be used, if the mucous membrane is to regain its normal condition and complete automatic activity is to be established. Finally, catheterization can be discontinued; urine accumulates in the bladder up to a volume different in each case, and of this a certain proportion is voided unconsciously at each act of micturition. In many cases some fluid remains behind, but occasionally the bladder appears to be emptied entirely.

Such is the condition that we shall investigate in this chapter. We hope to show that if the spinal cord recovers its functions after the first period of shock produced by the injury, it may pass into a condition in which peripheral extra-vesical stimuli not only produce an abnormally wide effect, but may even influence automatic evacuation of the bladder.

In three of the cases reported by Riddoch [7], where the spinal cord was proved to have been completely divided, this automatic condition of the bladder became established within the following periods from the date of the wound. In No. 1 it dribbled on the twenty-second day and a considerable quantity of the daily amount of urine was voided automatically by the twenty-fifth day; No. 3 was passing automatically by the twenty-ninth day, and No. 5 by the sixteenth day after the wound. If the spinal cord is less severely injured automatic micturition may be established within the first fortnight after the patient has been wounded, provided the local and general conditions are favourable. In gross sacral injuries, however, especially in lesions of the cauda equina, the appearance of involuntary micturition may be delayed for several months, and yet finally become fully established.

§ 1.—*The Activity of the Bladder-wall.*

In all attempts to measure the activity of an automatic bladder it is most important to avoid any considerable pressure. No results of any value can be obtained by raising the vessel containing the fluid to a height of several feet above the bed. The contractile power of the musculature is easily overcome and, if evacuation cannot occur at the

moment when tension becomes an effective stimulus, tonic contraction yields and the bladder accepts a further addition to its contents. Thus many a bladder, washed out by the customary method under considerable pressure, is thought to be passive and the urine passed into the bottle during the day is attributed to dribbling, although in reality the musculature is capable of expelling a considerable volume of fluid by automatic contraction.

Our observations on the functional capacity of the bladder in any particular case were made as follows. If possible we determined how long a time has elapsed since any urine has been voided automatically; a catheter was then passed and the amount found in the bladder measured. This varies greatly, but, as a rule, does not materially exceed the volume of fluid to which the evacuating mechanism was found to respond experimentally. A burette with a diameter of 4 cm. tapering to a narrow neck commanded by a glass stopcock, was attached directly to the opening of the catheter. Into this burette, which was graduated in cubic centimetres, was passed 100 c.c. of sterile slightly warm fluid, and the tap was turned so that the fluid could run through the catheter into the bladder. As soon as a back flow occurred, the burette was rapidly detached from the catheter and the fluid expelled allowed to pass into a flat dish held at a level just above the horizontal. During these manipulations the penis remained horizontal and the only pressure of fluid was due to that in the short burette held vertically.

The following observations made on No. 1, 158 days after total division of the spinal cord, will give some idea of the results we have obtained and the procedure adopted. Before passing the catheter the glans penis was carefully swabbed in the usual manner; this led to the immediate passage of 110 c.c. of urine, for in some cases this is a most effective method of stimulating reflex evacuation. On passing the catheter 340 c.c. were then drawn off. The bladder having been emptied completely, fluid was poured into the burette and when 600 c.c. had entered, automatic contraction began; he passed in all 595 c.c. and no more could be recovered by pressure on the abdomen. Fluid was again allowed to run into the bladder and at 600 c.c. was again evacuated to the amount of 590 c.c. Throughout these observations his bladder was astonishingly active; from the beginning the column of fluid in his tube showed oscillations which, on asking him to stop breathing, proved to be of respiratory origin. But after about 400 to 500 c.c. had entered the bladder, bigger oscillations began which culminated at 600 c.c. in a back flow; about 300 c.c. were passed at once,

followed, after a pause, by 200 c.c. Then came another pause followed by the expulsion of a smaller amount and finally when all activity had ceased he had passed in all 590 c.c. He was throughout unconscious of any of our manipulations or of the passage of fluid to or from his bladder. Moreover, he was quite unable to influence the evacuation in any way voluntarily, even through the abdominal muscles. At this time the urine was acid, slightly cloudy and contained no albumin; there was no deposit of pus or mucus.

Another series of observations made on the same patient 266 days after the injury, illustrates some of the reflex functions of the automatic spinal cord, in as far as they influence the activity of the bladder. It will be noticed that the capacity of the bladder was no longer so great as in the earlier stages, probably owing to the natural tendency of these automatic bladders to shrink, or to a febrile attack due to pyelitis from which he had suffered between the two sets of observations.

In consequence of the preliminary swabbing of the glans penis he passed 85 c.c. of urine and 200 c.c. were subsequently drawn off by catheter, giving a total amount of about 285 c.c. or 10 fluid oz. Sterile fluid was then allowed to run in through the catheter and at 180 c.c. he voided the total amount; nothing could be recovered by pressure. On a second observation, evacuation occurred at 210 c.c. and again he passed the whole amount. A third observation gave 240 c.c as the adequate stimulus and the bladder once more emptied itself completely.

Thus it was obvious that from 180 to 240 c.c. of fluid were required to evoke automatic evacuation through a catheter. We then allowed 100 c.c. of fluid to run into the bladder and stimulated the sole of the foot. This produced a characteristic flexor spasm, but the fluid was not ejected from the bladder. But on adding another 10 c.c. (110 c.c. in all) scratching the sole made the stimulus effective and 105 c.c. were evacuated by the contraction of the vesical musculature. A second experiment was carried out by running in 115 c.c. of fluid: scratching the sole produced no effect on the bladder, but on adding another 10 c.c. (125 c.c. in all) evacuation occurred immediately the flexor spasm was evoked. He passed 130 c.c. of fluid, an amount slightly in excess of that run into the bladder.

These observations show that an automatic bladder, which did not usually respond to less than 180 c.c. of fluid, could be made to eject its contents at a lower amount by evoking a flexor spasm. A stimulus to the sole of the foot, which should normally cause withdrawal of that

limb only, increased the automatic irritability of the bladder to such an extent that it responded to a considerably smaller volume of fluid.

Close association between reflex evacuation and the other activities of the spinal cord in this condition was well illustrated in the case of No. 2, in whom the spinal cord had been completely divided at the level of the fourth thoracic segment 218 days before the following observations were made. A catheter was passed and 175 c.c. drawn off. When 250 c.c. of fluid had run into the bladder evacuation occurred and 135 c.c. were voided; on pressure over the lower part of the abdomen a further 130 c.c. were recovered. But we noticed that this pressure did not act purely mechanically; for as soon as the hand was pressed upon the abdomen a flexor spasm was evoked. A second observation was therefore made as follows: Fluid was allowed to run into the bladder and at 290 c.c. it ejected 175 c.c. of its contents. The glans penis was gently pinched and a further 57 c.c. were passed; finally 70 c.c were recovered by pressure. In a third experiment we stopped at 250 c.c. just short of the point at which we knew the bladder would expel its contents; stimulation of the glans at once started the flow and 140 c.c. were ejected. Then a flexor spasm was evoked by scratching the sole and an additional 50 c.c. were passed; pressure produced the expulsion of another 90 c.c. The next observations were carried out somewhat differently: we inserted a certain volume of fluid, evoked reflexes and determined to what extent we could facilitate evacuation. Thus 100 c.c. were allowed to run in and the penis was stimulated without producing any return of fluid; but when 150 c.c. had entered the bladder, stroking the glans caused evacuation of 30 c.c. We also found that when the bladder contained 150 c.c. of fluid stimulating the sole of the foot at once caused detrusor contraction.

This shows that after complete division of the spinal cord, an automatic bladder which normally reacts to about 250 c.c. ("a 9-oz. bladder") could be made to expel its contents at a little over half that amount by evoking a reflex from the glans penis or from the sole of the foot. But in this case the expulsion was not complete; some fluid always remained behind in the bladder after the reflex had expended itself.

A similar condition was found in another case (No. 3) thirty-one days after total transverse division of the spinal cord. He began to return the fluid from his bladder at 350 c.c., voiding 350 c.c.; 5 c.c. were recovered by pressure over the abdomen. On the next observation the bladder expelled its contents at 375 c.c., and on this occasion the

complete amount of fluid was voided, but 15 c.c. in addition were expelled by pressure, showing he must have passed some urine into his bladder. This proved that evacuation now occurred at from 350 to 375 c.c. provided the stimulus lay entirely within the bladder itself.

But if some additional reflex activity was evoked in the lower end of the severed cord, this amount could be greatly reduced. Fluid was allowed to run in through the catheter and the sole of the foot was stimulated. At 100 c.c. no change occurred; at 150 c.c. the fluid rose slightly in the tube but no evacuation took place, and another 50 c.c. were permitted to pass into the bladder. At 200 c.c., however, scratching the sole of the foot produced a brisk expulsion of 150 c.c. of fluid.

One of the most potent of these facilitating stimuli is deep breathing. The influence of respiration on ejection of the bladder contents has been thought to be purely passive; but we shall show that a single deep breath may start an automatic discharge which leads to steady and complete evacuation. This was particularly well illustrated by a series of observations made on the above-mentioned patient sixty days after division of the spinal cord.

He had not made water for four hours before our observations began, and on passing the catheter 250 c.c. were drawn off. When fluid was allowed to run in through the catheter three observations gave the following results. At 300 c.c. he passed 305 c.c., and a further 15 c.c. were recovered by pressure; at 395 c.c. he passed 390 c.c., and at 380 c.c. he passed 380 c.c. During the first observation it was obvious that the quantity voided distinctly exceeded that injected, and a few cubic centimetres of urine must have been secreted during the experimental period. We have usually found that when this occurs the third observation, as in this instance, shows a more perfect accord between the amount entering and that ejected from the bladder. Thus we can say that in this case the bladder emptied itself automatically through a catheter when its contents reached about 380 c.c.

When the sole was scratched and a flexor spasm induced rhythmically, the bladder emptied itself completely on one occasion at 185 c.c. and on another at 180 c.c. But when he was asked to take one deep breath as each 10 c.c. passed out of the burette, the column of fluid rose a little at 60 c.c. and the bladder emptied itself completely at 80 c.c. A second observation gave 60 c.c. as the point of hesitation and 70 c.c. as the amount at which evacuation occurred. This remarkable series of observations shows that a bladder, which did not respond until its contents amounted to about 380 c.c., could be made to evacuate

itself completely at from 70 to 80 c.c. if the patient drew a deep breath.

This effect of respiration was also seen in a series of observations made on another patient, 277 days after injury to the spinal cord in the region of the sixth dorsal segment. When the stimulus was solely due to pressure within the bladder he responded at 220 c.c. voiding 180 c.c., at 180 c.c. voiding 140 c.c., and at 200 c.c. voiding 130 c.c. If, however, a flexor spasm was evoked the response was facilitated and evacuation occurred at 100 c.c. A deep breath was however so potent an adjuvant, that the bladder contracted when 10 c.c. only had been allowed to enter, and the whole amount was ejected. This cannot be purely passive, for, before we awoke to the full significance of this method of aiding automatic evacuation, we had tested him in this same series at 70 c.c., when one deep breath caused him to void 50 c.c., at 50 c.c. and at 40 c.c., when the whole amount was passed, and then finally at 10 c.c., with the result detailed above.

In the cases we have described so far the lesion lay sufficiently high to abolish all consciousness of anything that happened within the bladder and urinary tract. In No. 6, however, the spinal cord was injured at the level of the fourth and fifth lumbar segments and the majority of the afferent fibres of the thoracico-lumbar system were still in connexion with the nervous system above the lesion. His bladder began to act automatically about four months after the injury and, when he came under our care, he was passing the whole of his urine unconsciously without the help of a catheter. This man was astonishingly accurate in his account of the sensation produced by fluid in his bladder, although he had no control over its ejection, or appreciation of its passage down the urethra. He knew with certainty when evacuation was going to occur and said: "I have a pleasant desire to make water, just as I had when my bladder was full before I was hurt." Thus it is obvious that the existence of perfect consciousness of tension within the bladder does not of necessity influence automatic involuntary micturition.

The amount of the spinal cord which lay below the lesion must, in this case, have been extremely small; and yet we were able to show that contraction of the bladder could be facilitated by suitable reflexes. No response could be obtained to scratching the sole of either foot, but we noticed that when he was pricked around the anal opening a definite reflex was evoked, although these parts, supplied from the lower sacral segments, were entirely insensitive. If fluid was allowed to run into his bladder through a catheter evacuation occurred at a volume which

varied considerably on different occasions, but was never less than 75 c.c. But if the anal reflex was produced, evacuation invariably occurred when 10 c.c. only had entered the bladder. Reflexes from above the level of the lesion, such as those evoked by scratching the thighs or abdomen, had no effect on the activity of the vesical musculature.

It must not, however, be supposed that this condition occurs only in cases of total transverse division of the spinal cord. If the disturbance of function is sufficiently severe and long-standing, and particularly if the general condition of the patient is favourable to recovery, the original retention may pass into a period of automatic action indistinguishable from that found in cases where the cord is completely divided anatomically.

No. 8 was particularly instructive from this point of view, because the two halves of the body were in a different condition and stimulation of the two soles had a profoundly different effect upon the action of the automatic bladder. He was hit in the left side of the neck on August 24, 1916. This produced complete paralysis below the level of the fourth rib on both sides with some weakness of the left hand and forearm. All sensation to prick, heat and cold was absent over the right lower extremity and right half of the body as high as the level of the nipple, but was not materially affected to the left of the middle line. Spacial recognition and appreciation of the vibration of a large tuning-fork were abolished on the right side up to the iliac crest and on the left side almost up to the fourth rib. Tactile sensibility was not materially affected. Knee-jerks and ankle-jerks were greatly increased, and ankle clonus was present on both sides.

This patient always knew when his bladder was about to empty itself and was conscious that it was being filled as soon as the contents reached about two-thirds of that necessary to evoke automatic action. He had no desire to micturate, but experienced pleasure when the urine was passed or when the bladder wash was automatically ejected. He could not, however, control the action of the bladder in any way. Eight months after the injury a series of measurements showed that the bladder ejected its contents at between 70 c.c. and 115 c.c. (115, 70, 90, 100) and that in each case evacuation was complete.

We then proceeded to test the effect on the activity of this automatic bladder of evoking flexor spasms; but this case differed fundamentally from those we have previously described, in that the two lower extremities were in a different condition of sensibility. He could not

recognize painful or thermal stimuli over the right leg, whilst in the left these aspects of sensation were not materially affected. On both sides knee- and ankle-jerks were exaggerated, ankle clonus was present and the plantar reflexes gave an upward response and flexor jerk. If, then, the right (analgesic) sole was stimulated vesical contraction occurred at 30 c.c. and the whole of this amount was expelled. Thus the production of a flexor spasm so facilitated the activity of this bladder that it was enabled to evacuate its contents at 30 c.c. instead of at 70 c.c.

When, however, the left or sensitive sole was stimulated during the steady inflow of fluid, nothing happened, in spite of the flexor spasms, until, at 70 c.c., he said: "It will fire off of itself in a minute," and back came the fluid into the tube. Flexor spasms evoked on the side where sensation was intact could not influence or facilitate the action of the automatic bladder. Local signature was present and the bladder was not affected by reflexes due to extra-vesical stimuli.

The difference in reflex local signature of the two lower extremities was also evident in the flexor spasms themselves. For when the analgesic (right) foot was scratched not only did the great toe move upwards but ankle, knee, and hip became flexed, the thigh was adducted and a strong contraction occurred in the muscles of the right half of the abdomen. Moreover, a distinct extensor reaction appeared in the opposite (left) leg; the great toe moved downwards, the ankle became extended and a distinct contraction could be seen and felt in the left quadriceps extensor.

Contrast this reaction with that which occurred when the sole of the foot on the sensitive (left) side was scratched in the same way. A violent flexor withdrawal occurred; the great toe moved upwards and the inner hamstrings contracted, but there was little or no movement of the abdomen and no crossed extension could be seen or felt. The reflex movement was violent and completely abnormal in form, but it was almost entirely confined to the affected limb. Such a flexor spasm had maintained its local signature and the energy evoked could not materially affect the activity of the bladder or other functions of the spinal cord. On the other hand the reflex elicited from the analgesic limb was unchecked, and not only spread widely but also facilitated the automatic evacuation of the bladder; the energy set free in this "massive response" rendered adequate a previously ineffective stimulus.

We have given instances of the mode of action of an automatic bladder arising after total and partial division of the spinal cord. But

this condition may also appear when there is reason to believe that the cauda equina has been destroyed. This we should have expected from the experimental observations of Goltz on a dog, in whom the whole lower end of the spinal cord had been destroyed. There is, however, one fundamental difference between the behaviour of an automatic bladder arising after a complete lesion of the cauda equina and the condition which appears in favourable cases after total transverse division of the spinal cord; reflexes cannot influence its activity in any way and even those evoked by stimulating the fully sensitive abdomen or thighs produce no effect.

For example, in No. 7, where the spinal roots from the second lumbar downwards were gravely injured, automatic micturition had begun within thirty-four days after the injury and we were able to make the following observations. When 225 c.c. of fluid had run in through the catheter, he evacuated 230 c.c.; evidently a small quantity of urine had been passed into the bladder during our manipulations. A second observation gave 220 c.c. as the adequate stimulus and he ejected this exact amount. Owing to the injury to nerve roots, no cutaneous or deep reflexes could be evoked from any part below the lesion. On scratching the abdominal wall evacuation occurred at 220 c.c., as before, and with deep breathing he rejected the fluid when 230 c.c. had passed into the bladder. The production of abdominal reflexes from above the level of the lesion produced, as might have been expected, no effect on vesical activity. In this case automatic involuntary micturition had been established under conditions which precluded the exercise of any reflex influence upon the expulsive activity of the bladder.

§ 2.—*Behaviour of the Sphincter Mechanism.*

So far we have considered the behaviour of the bladder-wall only and have eliminated the sphincter by making our observations with a catheter in situ. But many of these patients pass all their urine automatically and, in such a case, the act of micturition demands not only contraction of the bladder-wall, but also relaxation of the internal sphincter. Both the sensibility of the mucous membrane and the muscular contractions are sufficient to generate the act of expulsion and, in addition, this reflex response of the bladder is associated with the requisite inhibition of the tonic sphincter.

We have described the remarkable way in which any stimulus, capable of evoking a reflex from the spinal cord below the lesion, may

facilitate the reaction of the bladder-wall. These extra-vesical stimuli can also influence the moment at which the sphincter relaxes and so hurry automatic micturition.

But such observations are much more difficult technically to carry out than those we have discussed in the earlier part of this chapter. The volume at which the bladder-wall evacuates its contents must first be determined through the catheter in the usual way. Then a smaller amount of fluid is allowed to run into the bladder and the catheter removed; various stimuli are applied to the parts below the level of the lesion in the attempt to evoke the complete act of automatic micturition; and in some cases this is found to occur although the bladder contains a volume of fluid smaller than that to which it would otherwise respond.

Thus forty-four weeks after complete division of the spinal cord in the region of the sixth thoracic segment No. 1 was automatically emptying his bladder through a catheter when its contents reached 490 c.c. But when the sole of the foot was scratched evacuation occurred at 160 c.c., and with deep breathing it began as soon as 25 c.c. only had passed into the bladder.

Now we knew, from the clinical records, that this patient was passing a full quantity of urine daily into the bottle. It was obvious, therefore, not only that his bladder-wall could expel the fluid when it reached a certain volume, but that the detrusor stimulus must have been associated with inhibition of the sphincter. We had then to determine whether extra-vesical stimuli could facilitate this complete act of evacuation, when the catheter was removed and the sphincter allowed to have free play. We allowed 400 c.c. of fluid to run in and the catheter was removed; deep breathing produced no obvious result, but on scratching the thigh he passed 80 c.c. in a fine strong stream. When, however, the bladder contained 200 c.c. no stimulus of any kind led to micturition owing to the obstruction of the tonic sphincter.

In this instance the bladder expelled its contents with a catheter in situ at 490 c.c. But even when the catheter was removed and the sphincter came into action some fluid was voided at 400 c.c., if flexor spasms of the legs were evoked by scratching the thigh. This shows that extra-vesical stimuli can not only bring about premature contraction of the bladder-wall, but also coincident relaxation of the sphincter. It is, however, obvious that, even in this most favourable case, facilitation occurred much less readily when the sphincter was in action than when we had to deal with the activity of the bladder-wall only, and in

many patients it is impossible, owing to technical difficulties, to show that such facilitation occurs at all.

For instance, in No. 3, the bladder-wall evacuated its contents completely at 290 c.c. with the catheter in situ. We succeeded in spite of the technical difficulty in passing just short of 290 c.c. into the bladder and removing the catheter without evoking expulsive efforts; then deep breathing, stimulating the soles, and rubbing the belly all failed to evoke evacuation, although if the catheter had been in place and the sphincter thrown out of action, any one of these stimuli would have caused him to empty his bladder at 150 c.c. Thus in some cases it is impossible to prove whether or no such extra-vesical stimuli facilitate relaxation of the sphincter, because of purely technical difficulties in carrying out the experiment; the bladder-wall ejects its contents through the catheter before they have reached an amount capable of evoking the complete act of automatic micturition, even under the facilitating influence of mass-reflexes. And yet in many of these patients we know clinically that grasping the lower extremities, lifting them from a bed to a chair and other similar excitants of spasm will cause the bladder to be emptied, in some cases completely.

If the sphincter has been injured or unduly irritated by the passage of a catheter it may not relax at all in spite of powerful contractions of the bladder-wall. This condition is a fruitful source of abnormal reflex activity in the lower end of the spinal cord, which may be manifested in spasmodic movements of the lower extremity, contracture of the abdominal wall and, in some cases, an outburst of excessive sweating (No. 5).

But apart altogether from such irritation the early return of tone to the sphincter mechanism compared with the later recovery of detrusor activity gives the sphincter a dominance that is overcome only under the most favourable conditions. We have given an example of complete automatic micturition, consisting not only of contraction of the bladder-wall but of relaxation of the sphincter, in a case where the sacral roots were destroyed. It is therefore certain that even under such conditions the urine may be passed automatically; but it is no longer amenable to those reflex effects, due to activity of the distal portion of the spinal cord, which form the main theme of this paper.

§ 3.—*Conditions which influence the Functions of an Automatic Bladder.*

(*a*) *Influence of the nervous system.*—When once automatic micturition has been established after injury to the spinal cord, evacuation of urine is governed by three factors: the response to tension of the bladder-wall, the relaxation of the tonic sphincter and the effect of extra-vesical reflexes.

Now there can be no doubt, from the experimental evidence, that the act of micturition can occur when the bladder is entirely separated from the central nervous system, or when the whole of the lower portion of the spinal cord has been destroyed. We have given an instance where a patient with destruction of the sacral nerve roots passed urine involuntarily and ejected fluid run into the bladder through a catheter as soon as it reached a volume of from 220 c.c. to 230 c.c. Under these conditions the spinal cord can exert no influence on micturition; involuntary expulsion takes place in consequence of the activity of structures outside the central nervous system. Our observations tend to support the views of those experimental physiologists who have shown in animals that the condition known as an automatic bladder may arise independently of the spinal cord.

But we have been able to show that, even when the spinal cord is completely divided, afferent impulses reaching the parts below the lesion may have a profound effect on automatic evacuation of fluid by the bladder-wall, and even, in some cases, on the complete act of involuntary micturition. Scratching the sole of the foot, the groin, or the abdomen, swabbing the glans penis and almost any manipulation capable of evoking reflex spasm, tend to facilitate the automatic activity of the bladder. Under such conditions the activity of the lower end of the spinal cord has obviously changed its character; the reflexes have lost their local signature and the energy excited by an afferent impulse from any one receptive field produces a profound general modification of all its functions. A stimulus that would normally evoke withdrawal of the foot tends also to facilitate automatic evacuation, and conversely injection of fluid into the bladder may be associated with a flexor spasm of the legs.

It has sometimes been taught that the form assumed by automatic micturition depends on the situation of the injury to the spinal cord. This is not borne out by our observations. Given that the lesion is sufficiently severe and the conditions both local and general are favour-

able, the reaction of the bladder-wall to endo-vesical tension will be the same in principle whatever the situation of the lesion. Of this we can be certain because our experience is based on measured observations. When, however, we are dealing with the complete act of involuntary micturition, we are forced to rely to a greater extent on clinical observation, and cannot state so definitely that the situation of the lesion in the spinal cord is entirely without effect. But we have brought forward instances where the spinal cord was injured in the most various situations between the seventh cervical and the twelfth thoracic segment, and yet the phenomena of automatic evacuation were identical in character.

In some cases when the lesion is situated below the tenth thoracic or is not sufficiently severe to destroy all sensibility, the patient may be conscious of tension within his bladder and yet be unable to influence voluntarily automatic evacuation. No. 6 was conscious that fluid was entering his bladder, he knew the moment at which the wall contracted, and experienced both the discomfort of distension and the pleasurable relief following the expulsion of the fluid; and yet these sensations did not in any way modify the act of involuntary evacuation.

(*b*) *Influence of shock, fever, and other general states.*—Long-continued cystitis tends greatly to diminish the size of the bladder, and at any rate in the earlier stages, to decrease the completeness with which it is evacuated. But, apart from such local inflammatory conditions, the fact that it is acting automatically seems to lead to a smaller capacity. This is not to be wondered at, and it is in agreement with Elliott's experience in animals, where cystitis is a rare event. For under normal conditions in man desire to micturate may be resisted; the bladder then resumes a new tonic position, and it is not until the quantity of urine has reached a very large amount that pain of necessity compels its expulsion. In the case, however, of the automatic bladder, all voluntary control is lost, and, as soon as the endo-vesical tension becomes an adequate stimulus, expulsion occurs. But it must be remembered that even in our experiments, made with the least possible pressure, there appeared moments when the bladder hesitated on the brink of evacuation, but finally accepted a further addition to its contents. If this happens when the sphincter mechanism is thrown out of play, it is still more likely to occur during the complete act of involuntary micturition, which demands not only contraction of the bladder-wall but coincident relaxation of the sphincter. It must often happen that urine collects in the bladder to an amount sufficient to

excite muscular contractions, but inadequate to inhibit the sphincter; the stimulus then dies away and the vesical tone yields to allow the assumption of a larger volume. Here, however, comes in the value of that remarkable facilitation, due to extra-vesical stimuli, of which we have so frequently spoken. The patient has only to turn on his side or to have an access of reflex spasms, for the contents of the bladder to become an adequate stimulus to micturition; and it is probably for this reason that, in favourable cases, the volume of fluid to which the bladder-wall responds in our experiments corresponds approximately to the amount at which involuntary micturition occurs. This can never be ascertained with certainty. For although it may be measured by removing the bottle as soon as the patient has passed urine, there is no means by which we can be certain that these measurements are typical. We shall, therefore, confine ourselves to describing the effect of general conditions such as shock, fever and toxic states on the volume of fluid to which the bladder-wall reacts with the catheter in situ; for this is a measurable quantity and can be determined with considerable accuracy.

Any severe febrile disturbance, whether it be due to a septic bed-sore or to pyelitis, tends to diminish the volume to which the bladder-wall responds. Provided, however, that cystitis is absent, or present to a small extent only, evacuation may still be complete. The more severe the cystitis the greater will be the difference between the amount of fluid run into the bladder and that which is expelled in any one observation.

No. 1 is a good example of the effect of a febrile disturbance uncomplicated by cystitis; 158 days after he was wounded his bladder responded to 600 c.c., expelling from 590 to 595 c.c. spontaneously. At this time his urine was acid and contained no pus or albumin. He then passed through a febrile attack with rigors, apparently due to pyelitis. This passed away entirely and did not recur. But on the 266th day after he was shot, measurements showed that the capacity of his bladder had diminished: he now responded to from 180 to 240 c.c., but still emptied his bladder completely. Fifty days later (306th day) the capacity had increased to 490 c.c., and during the next week a series of measurements gave from 420 to 425 c.c.; on both occasions the bladder was emptied completely.

This is, however, an unusually favourable case; more commonly repeated febrile attacks, with or without cystitis, diminish the capacity of the automatic bladder until it holds less than 150 c.c., and even this amount is incompletely evacuated.

Attacks of septicæmia, whatever their origin, greatly delay the establishment of automatic micturition. Thus another patient arrived at the hospital suffering from characteristic pyrexia, due to a foul bed-sore, and, although the bladder-wall responded to between 270 and 280 c.c. within forty-eight days of the wound, no spontaneous involuntary micturition has yet occurred after six months.

Now it is obvious that if a patient suffers both from cystitis and general septicæmia, true automatic micturition may never become established. Usually his bladder is washed out once or twice daily under a fluid pressure of two or three feet or from a large syringe; no attempt is made to determine whether his vesical musculature can respond or not, and he passes to his death as a case of retention with atony. It is therefore of extreme practical importance to discover in every case if the bladder is capable of reacting and expelling its contents; if so, it must be washed out with a suitable lotion under the least possible pressure. As soon as the fluid begins to rise in the tube it must be allowed to escape freely. In this way we can not only treat the cystitis, but at the same time encourage the muscular response of the bladder, even before the complete act of involuntary micturition has been established.

Apart, however, from the evil effect of toxæmic states on the automatic bladder, all febrile conditions tend to diminish the responsive power of the severed spinal cord. The distal end, separated to a greater or less extent from the influence of the higher centres, is peculiarly susceptible to the devitalizing influence of long-continued toxæmia.

This is strikingly evident in the behaviour of the reflexes. The receptive field diminishes and at the same time a stronger stimulus is required to evoke a response. At one period in the progress of the case it was perhaps possible to produce a flexor spasm by scratching almost any part of the lower extremity; but after long-continued fever it may be difficult to obtain a reflex even from the sole of the foot. The knee-jerk may diminish, ankle clonus disappear and even the so-called "spontaneous" spasms of the legs may become negligible. In cases of partial lesions of the spinal cord any extensor activity that may have existed is first eliminated; then the flexor contractions decrease in severity and frequency. All the signs point to progressive diminution of the tonic activity of the distal end of the injured cord.

With this deterioration in function the facilitating influence of extra-vesical reflexes disappears; a flexor response no longer makes it easier for the automatic bladder to discharge its contents. The sphincter

mechanism is very little affected and passive dribbling of urine and faeces occurs just before death only. Thus it is possible for a patient subject to prolonged febrile attacks to pass through, in the terminal phase, a period of retention of urine, owing to diminished detrusor activity associated with want of inhibition of the sphincter.

This downward progression under the influence of toxæmia is the reverse of the stages by which the lower end of the spinal cord regains its functions during recovery from the shock of the original injury. From the first the sphincters are little affected; there is complete retention of urine and the anus is not patulous; knee-jerk, ankle-jerk and ankle clonus are absent; the plantar reflex either cannot be obtained at all or consists of a downward movement of the great toe. Then involuntary micturition appears and the deep reflexes return. The plantar reflex assumes the abnormal form, and the field from which it can be obtained widens until it can be elicited by scratching almost any part of the lower extremity.

If the injury to the spiral cord has not been very severe, sensation and voluntary power may return and the phenomena of facilitation may never appear. But if the cord is completely divided or very grossly injured, the reappearance of tone, as shock passes away, may be accompanied by the conditions we have described as facilitation. All reflex activities have then lost their local signature. A flexor spasm of the leg can be excited by scratching not only the sole of the foot but almost any part below the lesion or even by injecting fluid into the bladder or rectum. Any adequate stimulus to any receptive surface is liable to evoke a massive response, which overflows widely into regions of the spinal cord normally associated with other reflexes. This development of the spinal tone and the advent of a condition in which an effective stimulus facilitates all reflex activities of the severed cord, are hindered or rendered impossible by general toxic states. Then the phenomena associated with the first period of shock do not wear off, and the patient may die without having presented any of those reactions, which are of primary interest to us in this paper.

Chapter II.—Excessive Sweating.

§ 1.—*Description of the Phenomenon of Excessive Sweating.*

Excessive sweating usually appears in its most striking form when the lesion is situated in the lower cervical region. Let us choose a case where sufficient time has elapsed since the injury for the deep reflexes

to have become exaggerated and for involuntary movements, of which the patient is unconscious, to occur, especially on manipulation. The period of shock has passed and the patient's general condition is sufficiently good to permit of the return of reflex excitability in the spinal cord below the lesion.

When the patient sweats excessively he usually does so intermittently; there are periods in which the skin is no moister than it should be normally. In such cases it is possible to make direct observations on the causes which evoke the hyperidrosis. These are remarkably various and we have found that there is scarcely a stimulus, cutaneous, proprioceptive, or visceral, that may not be followed by an outburst of sweating over the area appropriate to the lesion in each patient.

So long as the weather is cool and he is undisturbed, the skin of the head and neck may be moist to the normal degree but no more. If, however, the hand is placed under the bedclothes and flexor spasms, which the patient cannot appreciate, are evoked, either by scratching the sole of the foot or by grasping the lower extremity, beads of sweat may appear on his forehead. He knows nothing of the movement and stimulation of the feet can cause no sensation; and yet it may be sufficient to evoke profuse sweating limited to an area which is constant in each case and is determined by the site of the lesion and not by the situation of the stimulus.

Such patients usually require catheterization and, in many cases, the bladder must be washed out daily. These manipulations may be associated with extreme sweating over the head and neck. Moreover the patient recognizes that if the bladder is allowed to become too full and the passage of the catheter is delayed, the sweating will certainly begin. In the same way, at a time when the bladder is evacuating itself automatically, any obstruction to the flow of urine starts the local sweating and we have been able to evoke it experimentally by the injection of fluid during our systematic observations on the reflex capacity of the automatic bladder.

Any intestinal disturbance such as flatulence, and more particularly the manipulations for administering an enema, may start sweating in every way identical with that described as arising spontaneously.

When fully developed, the sweating in such cases is incredibly profuse; a dry sponge used to wipe the face and neck can be wrung out, as if it had been dipped into water, and blankets and pillows are soaked through with the moisture in a few minutes. So much fluid may be lost that the patient suffers from thirst and the urine is diminished in amount.

The extent of the area occupied by the excessive sweating differs according to the situation of the lesion; when the injury is in the lower cervical region it occupies the whole head, neck and arms, extending to about the level of the umbilicus, decreasing in amount from above downwards, and the legs may remain dry. A lesion at the level of the third thoracic segment may cause profuse sweating over both arms, over the whole trunk from the second rib down to the toes, with a maximum hyperidrosis in the upper dorsal region, steadily diminishing as we pass downwards towards the feet. The head and neck do not participate in the sweating.

If the lesion lies in the region of the sixth thoracic segment sweating may occur from about the fifth rib downwards with some moisture of the palms of the hands. Arms, neck, and head, however, remain unaffected.

With a lesion at the level of the eighth thoracic segment, sweating may occur from the ensiform down the thighs, diminishing greatly to the feet.

When the injury is situated at about the ninth thoracic segment, the area occupied by the hyperidrosis corresponds almost exactly to that of the analgesia, whilst at any point in the spinal cord below this the area of sweating is less extensive than that of the loss of sensation. Thus in a case where the left half of the spinal cord was completely divided at the level of the tenth dorsal segment, excessive sweating extended on the left lower extremity up to Poupart's ligament, but was never observed on the right leg. Here the left-sided sweating could be particularly easily evoked by any abnormal tension in the bladder.

§ 2.—*Conditions which excite it.*

We will now consider these definte causes for an outburst of excessive sweating one by one.

(*a*) *Reflex spasms.*—These can be studied in their simplest form when the period of involuntary automatic action has been fully established after complete division of the spinal cord. Thus, in the case of No. 1, where the lesion was situated in the mid-dorsal region, excessive sweating began forty-five days after the injury. It occupied an area extending from about the fifth rib downwards, with some moistening of the palms of the hands. If, when the skin was dry, the sole of the foot was stimulated, as he lay quietly in bed, a series of flexor spasms could be evoked; the toes became extended, the ankle dorsiflexed and both

knee and hip were vigorously bent. After two or three such spasms the sweating began and continued for a considerable time after he had been left at rest.

In No. 5, the lesion, though severe at the level of the seventh cervical segment, was not complete; but the association between the sweating and reflex spasms was most definite. If a suitable opportunity was chosen when the skin was in a normal condition, it was only necessary to scratch the sole of the foot under the bedclothes for the most profuse sweating to break out over the whole of the head and neck in association with the flexor spasms. These reflex movements could be evoked by stimulating almost any part of the skin of the lower extremity or abdomen by pressure, as in turning or moving him in bed, or even by lifting the bed-clothes. No matter how the spasms were produced, they were associated with an intense outburst of sweating over the head and neck.

No. 2 was another example of the close association between hyperidrosis and the existence of these spasmodic involuntary movements. The spinal cord was completely divided in the region of the fourth thoracic segment and the sweating occurred on the trunk from the level of the second or third rib downwards to that of the ensiform and usually affected the greater part of both upper extremities. Scratching almost any part of the lower extremity, grasping the foot or the muscles of the thigh, even removing the bed-clothes would start flexor spasms which were immediately followed by an outburst of sweating.

We could quote many other examples of this association between spasmodic movements and excessive sweating which may appear when the activity of the spinal cord has reached this stage of functional recovery. Analysis shows that in this condition the reflexes have lost their preponderant local signature; scratching the sole of the foot leads, not to a simple withdrawal, but to a universal flexor spasm which may extend to the opposite leg and is usually associated with a strong contraction of the abdominal muscles. Stimulation of almost any part evokes a spasmodic "mass-reflex" which remains more or less identical in character whatever the stimulus and wherever it is applied.

It is the production of this undifferentiated "mass-reflex" which in suitable cases is associated with the appearance of excessive sweating, but the reflex spasms are one only of its many associated conditions.

(*b*) *The activity of the bladder.*—It has long been known, at any rate to intelligent patients, that the condition of the bladder has a direct bearing on the sweating. But it was not until we began our

systematic measurements of the capacity of the automatic bladder that the truth of this view could be demonstrated under experimental conditions.

For example, take the case of No. 2, where the spinal cord had been completely divided at the level of the fourth thoracic segment. A catheter was passed and after the bladder had been emptied warm fluid was allowed to enter slowly from the burette. When 250 c.c. had passed into the bladder, fluid began to return and he evacuated in all 135 c.c.; a further 130 c.c. was ejected by pressure on the abdomen. Two further observations under the same conditions showed that evacuation occurred at 250 c.c. and 290 c.c.

He was entirely unconscious of any of these manipulations; but as soon as we evoked automatic bladder action he began to sweat profusely from the clavicles downwards, the head and neck remaining dry. The whole extent of the arms sweated profusely; the trunk became wringing wet from the clavicles to the groin; thighs, soles and the back of the legs were also sweating heavily, but not so profusely as the arms, chest, abdomen and back. Here we were able to induce the hyperidrosis experimentally, over an area corresponding to the parts below the lesion, by distending the bladder with fluid.

No 5 was another instance of this close association between vesical tension and the onset of sweating. His lesion, though not mechanically a complete division of the spinal cord, was an extremely grave one in the region of the seventh cervical segment. By the time he reached the London Hospital, three days after the accident, the urine, though acid, contained thick ropy pus and several false passages had been made from which he bled when the catheter was passed. He had absolute retention of urine and it was necessary to pass a catheter every eight hours.

Shortly after his admission we began to notice outbursts of the most intense sweating, probably more profuse than in any other instance that has come under our observation. Sweat ran together into huge beads which rolled off his face and neck and moisture could be wrung out of a sponge, passed over his skin, almost as if it had been dipped into water. A towel used to dry his face was wetted through in a few moments. Gradually it became apparent that one of the most fruitful causes of these outbursts of sweating was a full bladder. He would become gradually conscious of a "fulness" in the head and of the increasing moisture of his face; by the time the house physician arrived to relieve him, the paroxysm was fully developed; but the

sweating ceased as soon as the tension within the bladder was removed by the passage of a catheter.

It must not, however, be supposed that the bladder was an inert bag. For although no urine could be voided without the help of a catheter, we found that with the catheter in situ vigorous evacuation occurred when fluid was allowed to run into the bladder. Thus forty-three days after the injury fluid was briskly ejected through the catheter when 300 c.c. had been slowly passed into the bladder, and of this amount he succeeded in evacuating 150 c.c. On a second observation he responded to 180 c.c., extruding 125 c.c. One hundred days after the accident a more extensive series of observations was carried out. A time was chosen for passing the catheter when he was perfectly comfortable, and the skin was in a condition of normal moisture; 190 c.c. of urine were drawn off. On pouring fluid into the bladder the column began to oscillate at 150 c.c.; at 200 c.c. automatic evacuation began and he passed 120 c.c. A further 80 c.c. was recovered from the bladder by pressure on the abdominal wall. The first signs of sweating appeared on the forehead when 50 c.c. had entered the bladder and steadily increased up to evacuation. His face and neck were then dried and after some minutes the sweating had greatly diminished. Fluid was again poured into the bladder; the oscillations in the column began at 50 c.c., and at the same moment a fresh outburst of sweating occurred. At 120 c.c. the bladder contracted vehemently and extruded 70 c.c.; a further 95 c.c. was recovered by pressure on the abdomen, showing that some urine must have entered the bladder in the meanwhile from the kidneys.

Two further observations were made, after a sufficient pause during which his face and neck were carefully dried. He evacuated at 150 c.c. and at 125 c.c., passing 100 c.c. and 65 c.c. respectively. On the first occasion the sweating began when 100 c.c. had entered the bladder, whilst in the second it started at 70 c.c. One of the most striking features of this experimental series was the way in which the steady inflow of fluid was checked and began to oscillate at a definite point, showing that the bladder was no longer a passive receptacle, but was responding tonically to the stimulus of pressure. This was the signal for the outburst of sweating.

He was able to recognize with extreme accuracy the moment at which sweating first began. Thus, although he could not appreciate any of our manipulations, he would call, "Now the sweating is beginning"; and this corresponded to the moment at which fluid no

longer flowed freely into the bladder. When fully developed, the hyperidrosis occupied the head, neck, arms, and extended in an intense degree to the level of the ensiform; to a less degree it was found as low as the umbilical line.

In this case other peripheral stimuli could be made to evoke an outburst of sweating, but abnormal conditions of tension in the bladder were the most frequent and potent cause of "spontaneous" hyperidrosis. The urethra had been injured before he came under our care by unskilled catheterization; this had induced local irritation of the sphincter, which fell into spasm, and did not relax when the automatic contractions of the bladder came on. Consequently, when a certain amount of urine had collected, and the tension had been raised sufficiently, the vesical musculature responded, but, as the sphincter did not relax, no urine was passed. Then began a steadily increasing stream of afferent impulses, which started the sweating. We found experimentally that the bladder-wall responded to about 150 c.c. of fluid; had the sphincter been uninjured, it might have relaxed at about this point, and urine would then have been voided automatically. But the irritability of the sphincter led to perpetually recurrent obstruction, with distension of the bladder, above the amount at which reflex evacuation should have occurred. This was why the recurrent attacks of hyperidrosis could be infallibly relieved by passage of a catheter. Finally, we tied a catheter into the bladder, and fixed a cork into the orifice; the nurse could then allow the urine to flow whenever he complained of the sweating. This gave great relief, the irritability of the sphincter gradually subsided, and he began to pass urine automatically two hundred and eight days after the injury, and after the catheter had been in position permanently for nearly eight weeks.

No. 8 was another example of the close connection between exaggerated sweating and the condition of vesical tension. Here the lesion in the neighbourhood of the eighth cervical segment was functionally incomplete; he was, in fact, an instance of modified Brown-Séquard paralysis, with some diminution of power in the left hand and total loss of sensibility to pain, heat, and cold over the right half of the body from the level of the fourth dorsal segment downwards. The want of appreciation of vibration was, however, complete on both sides up to the level of the iliac crest, and on the left half of the body extended to the fourth rib.

This patient was much more conscious of our manipulations, and not only recognized that fluid was passing into the bladder, but could tell

when it was about to empty itself. He knew that the urine was coming, and when it passed experienced the normal pleasure, but he had no direct desire to micturate. When, however, there was any difficulty or obstruction in the passage of the water, sweating began at once. Thus it was not unusual for a plug of muco-pus to obstruct the orifice, so that the flow was rendered more difficult, and he would then begin to sweat profusely over the head and neck, the arms, and upper part of the chest. During the first three weeks this was confined to the right side, but later it became almost equally profuse on both halves of the head and neck.

Experimentally his bladder was found to respond to from 100 c.c. to 115 c.c., and the whole amount was ejected automatically. So long as the catheter was properly inserted, and the fluid could be evacuated freely, at the moment when the bladder-wall began to contract, no sweating occurred; but as soon as there was any obstruction, it began profusely over the whole head and neck. After the bladder had been opened suprapubically, all excessive sweating ceased, except when the box ("tortoise") shifted, or the free flow of urine was checked by some mechanical defect. On one occasion the drainage tube became blocked by a small calculus, and the hyperidrosis came on again in a violent form to our profound bewilderment.

This patient also showed that the excessive sweating is not correlated with that "thrill," or "shiver," which normally accompanies evacuation of a full bladder. In fact, this sensation seems to be evoked by the opposite condition to that which caused sweating. He could tell with remarkable accuracy when his bladder was about to empty itself during our experimental observations, and contended that he "always knew by a nervous wave, which seemed to start in his abdomen, and passed up to the head and down his arms"; it was "a sort of shiver," and it immediately preceded passage of urine automatically into the bottle or evacuation of the fluid inserted through the catheter. With this sensation he never sweated; it was always associated with an easy passage and free outflow. Any obstruction destroyed this sensation, and replaced it by sweating, which was accompanied by a definite feeling of discomfort.

(*c*) *Intestinal conditions.*—The patient (No. 1), who has been throughout our classical example of the consequence of a total transverse lesion of the spinal cord, soon discovered that he was completely ignorant of anything that happened within his gastro-intestinal canal below the stomach. He fully appreciated the passage of food down the

œsophagus and, being a heavy eater, recognized when his stomach was distended; but beyond that point nothing that happened affected his consciousness directly. We observed, however, that the injection of an enema was a potent cause of sweating. The lesion was at the level of the sixth dorsal segment, and head, neck, shoulders and arms with the exception of the hands always remained dry. But from the level of about the fourth rib downwards and on the palms the sweating broke out profusely when fluid was injected into his lower bowel.

Like the bladder, the rectum evacuated its contents automatically. Dribbling of fæces was never known to occur. When an enema was given the amount of fluid necessary to start an evacuation depended on the quantity of fæcal matter already in the rectum; it varied from 50 to 250 c.c. (2 to 9 oz.). As soon as the adequate quantity of fluid had been injected, the sphincter relaxed and fluid and fæces were voided together; sometimes, however, several small evacuations occurred but there was no constant dribble. The rectal wall contracted on its contents and expelled them vehemently. Sweating rapidly ceased as soon as the rectum was acting freely.

No 5 was another splendid example of the relation between intestinal tension and hyperidrosis; for not only was the sweating infallibly evoked in profuse quantity by an enema, but any collection of wind would also tend to produce an outburst. In the earlier days, before the catheter was tied into his bladder, he was peculiarly liable to periodic gastro-intestinal attacks associated with nausea and the collection of intestinal flatus; the abdominal muscles became rigid, flexor spasms increased in the legs and the sweating became very severe. Anything that eased this flatulence or the advent of the natural termination of the attack was associated with a diminution in the sweating. But, whatever the reflex cause, the distribution of the hyperidrosis was the same; it occupied the head, neck, arms and the trunk to the umbilical level.

In the case of No. 8, where the clinical picture was that of a modified Brown-Séquard paralysis, this relation between intestinal tension and excessive sweating occurred only when evacuation was not completely free. He was analgesic and thermo-anæsthetic over the right half of the body as high as the nipple level, but was sensitive to pain and thermal stimuli over the left half of the trunk. When an enema was given in my presence he said he could feel the insertion of the nozzle of the syringe. Then after the first few ounces of fluid were pumped in, he said, "I have a feeling as if the passage were being

forced open"; after receiving about 300 c.c. he said: "I've got a nervous feeling which runs up the body down my arms into the back of my head and over the front of the scalp: it also runs down the front and inner aspect of both thighs more on the left (sensitive) side than on the right. This thrill is not unpleasant, but as the injection goes on it becomes unpleasant, just as it is unpleasant when you have to strain at stool." No sweating occurred until this thrill became converted from a pleasant to an unpleasant sensation, a condition exactly analogous to the similar phenomena produced by obstructed evacuation of urine (*vide* p. 213). The pleasant visceral thrill is not associated with a stimulus to sweating; but obstruction, with its natural discomfort, evokes hyperidrosis.

(*d*) *Heat.*—Changes in external temperature are liable to influence the amount of this local hyperidrosis. Thus No. 1 sweated less when he was sitting up in a chair, and the act of putting him back to bed and wrapping the blankets around him caused a profuse outburst of moisture over the whole of the usual area. When he was lifted out of a warm bath sweat poured from the lower half of the chest, abdomen and palms.

But as soon as the change in temperature is due to some general febrile cause, such as septic infection from the bladder, kidney, or a dirty bed-sore, the sweating becomes general. It is true that in some instances the area peculiar to each case is still found to be moister than the other parts of the body; but the difference between the condition produced by a hot bath and that which accompanies a febrile attack is most striking.

Thus in one patient, where the left half of the spinal cord was divided at the level of the eleventh thoracic segment, the sweating occupied under normal conditions the left lower extremity only. He suffered from a febrile rise of temperature, and the sweating was universal, though more profuse over the left leg. Similarly aspirin causes general sweating in these patients, although at the time they may be free from fever.

§ 3.—*Distribution of the Sweating and its Significance.*

It is now universally recognized that the secretion of sweat is brought about by the sympathetic system, and that the connector fibres, conveying these motor impulses to the sympathetic chain, pass from the central nervous system by way of the anterior roots. Langley [3] showed that all the fibres capable of evoking sweating left the

spinal cord between the second thoracic and third lumbar roots, that is in the thoracico-lumbar outflow, to which he strictly confines the term sympathetic. This use of the word has now become so universal amongst physiologists that we shall adhere throughout this paper to his nomenclature; whenever we speak of "sympathetic" we shall signify some activity or structure pertaining to the thoracico-lumbar outflow.

It will be obvious that if a patient sweats excessively after an injury to the spinal cord, the impulses on which the hyperidrosis depends must pass out between the second thoracic and third lumbar segments. Now, in such a case as No. 5 the lesion was situated in the sixth and seventh cervical segments of the spinal cord and sweating of the most profuse character occupied the whole head, neck and trunk as far down as the umbilical level. The essential cause of this phenomenon must, therefore, have lain in the spinal cord below the injury.

We have also been able to demonstrate that this sweating can be evoked by the most various afferent impulses affecting the spinal cord below the lesion only. For scratching the soles of the feet or filling the bladder with fluid are stimuli which can act solely on the distal parts of the divided cord.

It is thus obvious that, in the instance we have given, the cause of the hyperidrosis must be sought below the lesion, and when we examine case by case the area occupied by the excessive sweating in the light of our present knowledge of the sympathetic system, we are driven to the same conclusion, however improbable it may seem on superficial consideration. In the two patients (No. 2 and No. 3) where the cord was divided at the level of the fourth thoracic segment, the sweating was profuse over the upper extremities, the post-axial being moister than the pre-axial parts, and over the trunk from just below the clavicles to the thighs, or even to the toes; the head and neck were entirely unaffected.

Now Langley had shown that in the anterior extremity of the cat sweating is determined by fibres which leave the spinal cord from the fourth to the ninth thoracic roots. Thus the distribution of the hyperidrosis in our two cases where the cord was divided at the fourth thoracic segment also points to some cause below the lesion, in spite of the fact that sweating occupied the upper extremities.

In No. 1, the patient with complete transection of the spinal cord at the level of the sixth thoracic segment, the sweating occupied an area from the fifth rib downwards, and to a less degree affected the palms of the hands. Now, of the seven thoracic roots which govern the upper

extremity, three are certainly at or above the lesion in this case; four are, however, below and account for the moisture of the palms.

When the lesion lies at about the eighth or ninth thoracic segment the sweating corresponds almost exactly with the analgesia; it no longer extends far above the parts that are insensitive, as in the previous cases.

As soon, however, as the injury lies at a point below about the ninth thoracic segment, the hyperidrosis, should it occur, does not extend as high as the corresponding loss of sensation. Thus, in a case where the left half of the spinal cord was divided at the level of the eleventh thoracic segment, the sweating occupied the left leg and lay entirely below Poupart's ligament, whilst the analgesia extended to just below the umbilicus.

This, again, corresponds exactly with Langley's results in the cat; for he found that the posterior extremity was supplied from the eleventh, twelfth and thirteenth thoracic, and first and second (slightly third) lumbar roots.

Our observations show that, in every case belonging to the group we have described in this paper, the excessive sweating must have been due to processes occurring in the spinal cord below the lesion. For not only could it be evoked by the most diverse stimuli to the lower limbs, but also by changes in tension within the bladder or lower part of the intestine. Moreover, analysis of the distribution of the excessive sweating in each case shows that it corresponds to some abnormal activity in parts of the central nervous system below the injury. Here will be found the key to the final causation of this curious condition.

Chapter III.—Theoretical.

§ 1.—*The "Mass-Reflex" and its Various Effects.*

(*a*) *Conditions under which it appears.*—Under normal conditions every reflex shows signs of the receptive field from which it originated. Not only can we say that stimulation of a certain part will evoke a series of predetermined and orderly movements, which Sherrington has called a "type reflex," but the motor reaction may be modified by the position of the stimulus within the receptive field. Thus the sole of the foot forms the most favourable situation for inducing the flexion reflex consisting, in its full form, of flexion at the hip and knee and dorsiflexion of the foot. If, however, the outer aspect of the sole is scratched the foot is somewhat everted, whilst stimulation of the inner

side leads to inversion; and yet throughout the total movement of the lower extremity remains true to type. This is no more than an example drawn from clinical experience of Sherrington's experimental results on the scratch reflex. For whatever part is stimulated within a certain saddle-shaped area on the dog's back, the foot of the same side rises to perform the act of scratching; and yet the actual direction of the thrust is determined by the situation, within that area, of the spot that has been scratched. This gives the peculiar purposeful character inherent in so many reflex movements.

This tendency to modification in form according to the locality of the stimulus has been called by Sherrington the "local sign" of a reflex. The more accurately it is developed, the smaller will be the receptive field from which one set of movements can be evoked and the more certainly will those movements alone make their appearance. A discriminative and strictly regulated response to stimulation points to a high level of neural activity, and upward progress in the nervous system is shown in the replacement of diffuse "mass-reflexes," endowed with little local signature, by a highly organized and specific response. On the other hand, the tendency to answer by a stereotyped and diffuse outburst of motor energy, to stimuli differing widely in place and kind, is a sign that lower mechanisms are set free from control.

This lower grade activity is manifest in all the phenomena we have gathered together in this paper. Scratching almost any part of the lower extremity, or even the abdomen, may evoke a characteristic flexor spasm. Some remains of the old discriminative response may still be visible in the greater flexion at the hip, when the groin is scratched, than if the sole of the foot is stimulated; and there are other minor differences in the mass-reflex depending on the situation of the stimulus. But these are of little account in comparison with the stereotyped uniformity of the response, however widely the stimulus may have differed in nature and situation.

Moreover, the energy evoked overflows into channels with which the reflex manifestations are not associated normally. Stimulating the sole of the foot aids evacuation of the bladder, and conversely injection of the bladder with fluid evokes a flexor spasm. Such "mass-reflexes" form an excellent answer to noxious stimuli in lower organisms, but are useless for discriminative action. The whole tendency of development in the central nervous system is in the direction of restricting the diffusion of afferent impulses and controlling the form and extent of their reflex reaction.

When the spinal cord has been completely divided, without widespread destruction or septic infection, the lower end may, under favourable conditions, regain its tonic influence and reflex excitability. As shock disappears its various functions gradually return; but they now assume a form in which the reflexes have lost, to a great extent, their local signature, and the reaction is massive rather than specific. In order to study this condition experimentally, we have used three indicators: we have noted the change in the reflexes, more particularly from the lower extremity; we have measured the effective reaction of the bladder, and, when possible, have induced a reflex outburst of sweating by the application of various stimuli. All these methods of research have revealed the same alteration of functional activity in the separated end of the spinal cord. It will be well, therefore, to summarize our results under each of these headings before passing to more theoretical conclusions.

Shortly after the cord has been completely divided no plantar reflex may be obtainable, or, in the earlier stages, the great toe may move downwards. This form of response has been described by Gordon Holmes [2], and as it is discussed by Riddoch [7] it need not detain us here. Somewhere about the fourth week, in a favourable case, the great toe begins to move upwards when the sole is scratched. About the same time, or even before, contraction of the inner hamstrings can be felt. Step by step, as the condition of the lower end of the spinal cord improves, the response comes to consist of a vigorous flexion at the hip and knee, dorsiflexion of the foot, upward movement of the great toe and splaying of the other toes of the stimulated foot. As time goes on the rectus and other abdominal muscles participate and some crossed movement, usually flexion, occurs.

Not only does the reflex from the sole of the foot throw into action an abnormally large group of muscles, but the receptive field from which the reflex can be evoked is enormously extended; it can be produced by scratching almost any part of the lower extremity, especially the groin, inner side of the knee and outer aspect of the leg. Moreover, the great toe can usually be made to move upwards, and the inner hamstrings to contract by stimulating the wall of the abdomen, and not infrequently injection of fluid into the bladder or rectum produces a characteristic flexor spasm.

In the same way the abdominal reflex undergoes analogous changes. At first it may be possible to produce a local segmental reflex only. This gradually gives place to a vigorous general contraction of one half

of the abdomen, in which the rectus takes part, and to this may be added all those phenomena in the lower extremity which otherwise follow scratching of the sole of the foot. At this stage it matters little whether the abdomen, groin, knee or sole be stimulated; the response evoked is a "mass-reflex," or "flexor spasm," consisting of a series of widespread muscular contractions mainly, but not entirely, on the same half of the body as the site of the stimulus. The superficial reflexes have to a great extent lost their local signature; stimulation of one part of the body no longer causes its appropriate movement, but calls up much the same response, whatever may be the receptive field.

This indiscriminate activity in the lower end of the severed cord is also manifest in our measurements of the functional capacity of the automatic bladder. Provided there is little cystitis, pyelitis or general toxæmia, the bladder-wall rapidly recovers the power of expelling its contents through a catheter, when they have reached a certain amount. This condition can be reached in a bladder cut off from the central nervous system. But it is established more quickly and perfectly if it remains in connection with the lower end of the severed spinal cord. Once in full activity, under such conditions, the automatic bladder becomes a valuable index of the widespread effect of any adequate stimulus, applied to the parts below the lesion. Scratching the sole of the foot induced a bladder, which otherwise responded to 420 c.c., to eject its contents at 160 c.c. The same facilitation may occur whatever part of the body is stimulated, provided a flexor spasm is evoked, and, in some cases, the abdomen may be as effective a receptive field as the sole of the foot.

Deep breathing has a profound effect upon the activity of the bladder-wall. Of this we have given numerous instances; for example, No. 1 ejected 25 c.c. of fluid through the catheter under the influence of deep breathing, although the usual unaided response did not occur until the contents of his bladder had reached 420 c.c.

Pinching or otherwise stimulating the glans penis may also cause premature micturition, provided it does not produce erection. If, however, the penis becomes turgid under these manipulations, the sphincter mechanism is not relaxed and the bladder is not emptied.

Injection of fluid into the rectum, as during the administration of an enema, will also cause involuntary micturition. At the same time such distension of the lower bowel may evoke a characteristic flexor spasm.

When we examine the underlying causes of hyperidrosis in these

cases of spinal injury, the facilitating influence of almost any afferent impulse, affecting the lower portion of the cord, is strikingly evident.

An outburst of sweating can be evoked by stimulating the sole of the foot, or any part of the lower extremity capable of producing a flexor spasm. Injection of fluid into the bladder is a most effective stimulus and sweating is peculiarly liable to appear if the fluid has not free means of exit. Thus, when the bladder was opened suprapubically in No. 8, all paroxysmal sweating ceased, until the exit tube became blocked, when it reappeared as violently as ever. In the same way the injection of fluid into the rectum frequently evokes an outburst of sweating over the area customary to each particular case.

Such are the conditions which may arise in the lower end of an injured spinal cord. In order that it may fall into this manner of reaction the lesion must be gross, but need not be anatomically complete, and it is at first sight puzzling to discover the factors which determine its appearance. Some cases, where all sensation and power of voluntary movement are lost, do not show this general diffusion of reflex energy to a degree sufficient to hurry evacuation of the bladder, whilst others, with apparently less severe disturbance, show all these phenomena of facilitation.

In the next subsection we shall describe the reflex reactions in cases where the spinal cord was gravely injured, and yet no facilitation occurred, in the hope of determining the factors which underlie the assumption of this condition.

(*b*) *Conditions under which it does not appear.*—Before any hypothesis can be suggested, to explain why this overflow of reflex activity occurs in some cases and not in others, although interference with the functions of the spinal cord may appear, at first sight, to be equally severe, it will be necessary to compare one by one the characteristic manifestations of the two groups of cases. In those patients in whom we knew that the spinal cord was anatomically divided, and also in those where we had reason to believe that all conduction had been permanently abolished by the lesion, certain reactions failed to make their appearance in the lower extremities, even after the period of shock had passed away. Such are the cases which tend under favourable conditions to exhibit diffuse reflex activity and excessive facilitation. On the other hand, all voluntary power may be abolished and the patient may be insensitive to every form of stimulus below the level of the lesion; bladder and rectum may be acting automatically, and yet, if certain reflex responses are present, facilitation fails to appear in man, even under the most favourable conditions. [No. 4.]

The most important of these reflexes is primary extension of all the joints of the lower extremity, obtained by stimulating the thigh, groins and abdominal wall. Scratching, pinching, or rubbing any of these parts, to the right or left of the middle line, produces this extensor movement in the lower extremity of the same side; in some cases the reflex movement is bilateral, but it is always more extensive on the stimulated side. A condition, in the lower end of the injured spinal cord, capable of producing such a reflex, is, in our experience, incompatible with that diffuse response and excessive facilitation of visceral activity which form the theme of this paper.

Again, permanent extensor rigidity does not occur in man when the spinal cord is completely divided. Whenever extensor movements appear they are a transitory reaction to flexion in the opposite limb. But in cases of gross injury to the spinal cord, where all voluntary movement and sensation are abolished up to the pelvis and the bladder is acting automatically, one or both legs not uncommonly fall into extensor spasm and may even remain constantly in an extended position. Under such conditions evacuation of the bladder cannot be facilitated by any extra-vesical stimulus in spite of the severity of the spinal injury.

Sherrington ([8] p. 67) described a reflex of the dog's hind limb which he called the "extensor thrust," obtained by mechanical stimulation of the sole. This can be elicited in some cases of gross injury to the spinal cord by gently pushing up the front of the foot when the knee is resting passively in a position of partial flexion; the extensors of the knee and the calf muscles can be seen or felt to contract, and if a strong thrust is evoked the limb is momentarily straightened and the foot plantar extended. This reflex is in no way allied to an incomplete ankle clonus. For the extensor thrust, when fully developed, is a single quick movement extending over two joints, while ankle clonus is essentially a repeated movement due to action of the calf muscles only. We believe that the true extensor thrust cannot be obtained in man where the spinal cord is completely severed automatically or even functionally. Moreover, the existence of such a reflex is associated with an absence of excessive facilitation, however gross may be the loss of motion, of sensation or of visceral control.

Another condition sometimes present in these cases is the phenomenon of reflex stepping, described by Nothnagel in the frog, and systematically explored by Sherrington ([8] p. 65). In man it takes the following form: If one knee is placed passively into a slightly bent

position and the foot is sharply dorsiflexed the knee becomes actively straightened. This is the extensor thrust. It may be accompanied by flexion of the opposite knee and foot. This again may be followed by extension, and the legs may continue for some time to move rhythmically, flexion on the one side being accompanied by the extension on the other and vice versa; in fact the cord carries out reflexly the movements of stepping. This is another of the phenomena which appear to point to a condition of activity in the lower end of the injured spinal cord incompatible with excessive facilitation of a visceral reflex from a somatic receptive field.

When the cord has been completely divided and the general conditions are favourable for the establishment of a massive response, the receptive field of the flexor spasm spreads widely; not only are foot, knee, hip and abdomen thrown into contraction, but this reflex can be evoked by scratching almost any part below the umbilicus. But, when an extensor reflex can be obtained from the thigh as a primary response, this great widening of the receptive field does not occur, however much the loss of motion and sensation may point to functional division of the spinal cord. Scratching the groin, or even the front of the thigh, will produce a palpable contraction of the quadriceps extensor of the same leg. This reflex has been able to maintain itself against the invasion of its receptive field by the flexor response. Under such circumstances evacuation of the bladder cannot be facilitated from without.

Another curious difference occasionally present between the two sets of cases, grouped by these criteria, seems to be the patient's conception of the position of his legs. Select two men with gross injury to the spinal cord at the same level. Both may be unable to recognize the actual posture and movement, passive or spasmodic, of the lower extremities; and yet, if the extensor phenomena we have indicated are present, the patient tends to think his legs are lying straight out in front of him, whatever their actual position. On the other hand, the man in whom the mass-reflex, flexor spasms and facilitation are well developed usually says that his legs are flexed at the knee and often adds that his feet are drawn up to his hips.

§ 2.—*The Physiological Significance of these Conditions.*

In cases of gross injury to the spinal cord anywhere in the dorsal region we have shown that the presence or absence of sensation is not the determining cause of the subsequent development of a massive

response. Consciousness appears to play no essential part in determining whether it shall appear or not; for the patient may be insensitive to all forms of stimulation, however intense, and may be unable to appreciate the posture or movements of his lower extremities, and yet all signs of diffusion and undue facilitation may be absent. Reflex local signature is still maintained in spite of the grossest interference with every aspect of sensation.

In the same way voluntary power may be lost, including control of the bladder and rectum, without this condition necessarily making its appearance, even though sensation is also completely abolished. The key to the problem lies, we believe, in the significance of the extensor phenomena, which alone of necessity distinguish the cases of gross lesion to the spinal cord, where local signature is maintained, from those in which it is largely abolished.

Sherrington has shown that these extensor reflexes are associated with the maintenance of postural tone and the act of standing and walking. But he has also shown that the mechanism, on which they depend primarily, consists of intraspinal (proprio-spinal) arcs: the activity of this system cannot be immediately affected by stimulation of any one afferent root. The maintenance of postural tone demands an adjustment of the whole body and limbs. An essential feature of locomotion is the alternation of two converse phases of contraction and relaxation in the same muscle. This is beautifully seen in the reflex stepping of such a patient as No. 4; but it is equally apparent in the extensor thrust, which can be obtained in all that group of cases to which he belonged. The contraction of the muscles of the calf, which occurs when the foot is pressed upwards, is followed in the same extremity by a definite flexion of the foot; the reflex is in reality a biphasic movement.

We have every reason to believe, from Sherrington's experiments on animals and from Walshe's researches on man [9], that the control of these movements is situated somewhere in the midbrain and pons. It is closely associated with impulses from the semicircular canals. This ultimate controlling centre, presiding over postural tone in the absence of consciousness, acts on the spinal centres and is responsible in man for the appearance of primary extensor manifestations after injury to the spinal cord.

We should like to suggest that it does not act on the spinal centres for the fore-limb and hind-limb independently, but that these proprio-spinal systems are linked up intimately together. The functional state,

induced by the higher controlling centre is not a movement of one limb, but a change of posture of the body as a whole, requiring readjustment of every part of the animal. In the class of case with which we are dealing, we do not see this change elsewhere than in the lower extremities, because the parts above the lesion are still under the control of the will, which prevents any such purposeless manifestation.

But although the stimulus evoking these extensor phenomena has failed entirely to reach consciousness it has acted on the mechanism for postural tone; the synaptic resistance of the common path has been raised against undue flexor activity. There is no longer a straight and uninterrupted road from afferent receptor to flexor movements, but the synapse may be set towards extension or flexion according to the situation and nature of the stimulus. As at a junction on the railway, the points are locked, in many cases automatically, according to the nature of the message received.

Such automatic regulation of the approach to the common efferent path demands some difference in quality on the afferent side according to the site of the stimulus. This difference need not reach consciousness; the patient may not recognize that anything whatever has happened to his lower extremities, and yet the impulses generated by scratching the sole still differ from those caused by scratching the thigh by the fundamental characteristics due to their diverse locality. That is to say, they still maintain their local sign, and this gives to each reflex a form consonant with the local signature of the impulses which evoked it.

We agree entirely with Walshe in his view that primary extensor activity is not, in man, a function of the lower end of the transected spinal cord. The human lower extremities are so exclusively used for maintaining the upright position and for locomotion that the dominant activity of their neuro-muscular mechanism is the production of changes in postural tone. This requires a nice balance between flexion and extension and represents a high order of central control.

Uncontrolled flexion, on the other hand, as far as the lower extremities are concerned, still maintains its close relation with impulses, which would underlie pain or discomfort, if consciousness were present. The sole of the foot, even in man, must still be protected from injuries by stones and thorns, and the response is an immediate withdrawal of the limb that has been hurt. This is the essential flexor spasm, and it still retains many of the marks of its origin; it is more easily evoked from the front of the sole, and the most effective stimulus is a prick or a scratch. Such protective reflexes are the oldest in the phylogenetic

scale, and, wherever they still remain in the human organism, betray their primitive origin. Although the movements they evoke are normally strictly under the influence of higher control, the reflex mechanism upon which this influence acts belongs to the more lowly centres in the nervous system.

When, therefore, shock passes away, after complete division of the spinal cord, these lowly centres in the distal end recover their functions if the conditions are favourable. But, in man, this recovery does not occur as a part of the restitution of postural tone, but as an isolated capacity of responding to noxious influences (Sherrington's "nociceptive reflexes").

Now, intense pain or discomfort not only evokes a withdrawal of the lower extremity, but also leads to definite visceral reflexes; urine is passed, the rectum is emptied, and the sufferer sweats. This is particularly evident in fear, which plays upon the whole of this nociceptive reflex mechanism.

According to our view, the massive flexor response, which can be evoked from almost any part below the lesion after complete transection of the spinal cord, is not a part of the normal postural reflexes, but belongs to the ancient nociceptive mechanism. It has in this form nothing to do with standing or walking. Its nearest ally among the reflexes is not primary extension, but evacuation of the bladder and rectum.

On the other hand, when primary extensor activity reappears in the distal end of the spinal cord, flexion becomes controlled and modified as its direct co-relative in postural tone. Flexion may still be evoked under suitable excitation as a nociceptive response, but there is now a block on the reflex synapses to viscera, such as the bladder and rectum. This raised synaptic resistance may be overcome, as in normal life, if the stimulus is extremely violent, or if an emotion such as fear supervenes. But under usual conditions the calling up of a flexor reflex in one lower extremity is followed by an extensor phase, and vice versâ. Flexion in the presence of even automatic extensor activity is linked up with postural tone. Flexion in the absence of local signature and of postural tone reappears in the spinal cord as a nociceptive manifestation only, closely associated with visceral reflexes, such as evacuation of the bladder or rectum and excessive sweating.

The explanation we have put forward in this section is in the direct line of thought from the views enunciated by Hughlings Jackson from 1864 onwards. He laid down in many communications and in his

clinical teaching, that in lesions of the nervous system positive symptoms were usually the result of removal of control, normally exercised by higher over lower centres. When speaking of rigidity in hemiplegia he says: "My speculation is that the rigidity is due to unantagonized influence of the cerebellum. I believe that in health the whole of the muscles of the body are doubly innervated both by the cerebrum and cerebellum, there being a co-operation of antagonism betwixt the two great centres. Whilst the cerebrum innervates the muscles in the order of their action, from the most voluntary movements (limbs) to the most automatic (trunk), the cerebellum innervates them in the opposite order . . . . This is equivalent to saying that the cerebellum is the centre for continuous movements and the cerebrum for changing movements."

"The muscles which, on the above suggestion, are chiefly innervated by the cerebellum are those which have the fewest different, the most tonic, the most confluent movements; the reverse for those which the cerebrum chiefly innervates. Thus in walking the cerebellum preserves the equilibrium of the body, tends to stiffen all the muscles; the changing movements of walking are the result of cerebral discharges overcoming in a particular and orderly way the otherwise continuous cerebellar influence. This is what is meant by a co-operation of antagonism."

These views had little general influence on neurology until Sherrington's remarkable series of experiments led to a coherent conception of the relation of the innervation of flexors and extensors, particularly in the lower extremity. He proved that in the decerebrate animal all those muscles which maintain posture are in a condition of tone; these are mainly the extensors. But if the spinal cord is divided even in the upper cervical region all the reflex reactions which can be obtained are flexor; they do not lead to the assumption of posture, but are phasic movements. Now since the one form of activity is seen when all cerebral influence is removed by a lesion across the cerebral peduncles, whilst after transection of the cord the primary reaction in the stimulated limb is uniformly a flexor movement, it follows that the centre governing postural tone in the hind legs of the dog must lie somewhere in the midbrain or pons. On the other hand, the centre for the primary flexor response must lie in the spinal cord.

Such conceptions of integration within the nervous system had a profound effect on the younger English neurologists and led to the production of Walshe's paper [9] on reflex phenomena in paralysis

of the lower limbs in man. His conclusions can be summarized as follows:—

"(1) The reflex movements of the lower limbs in spastic paralysis are almost entirely movements of flexion of the limbs; with flexion is included dorsiflexion of foot and toes, more especially the hallux. These movements occur as the well-known flexor spasms in certain cases of paraplegia . . . .

"(2) The 'receptive field' of this reflex commonly includes the whole limb, skin and deep structures. The form of stimulus most effective is that having a nocuous or harmful character . . . .

"(3) Of this reflex flexion, dorsiflexion of the hallux is an integral and inseparable part . . . .

"(4) The physiological significance of the flexion reflex is that of a defensive reflex and it has no relation to 'spinal stepping.' . . .

"(10) The conditions of paraplegia in flexion is an example of unantagonized flexor reflex action."

Such are some of the conclusions drawn by Walshe from his study of the effects of cerebral and spinal lesions in man. It will be seen how directly they are based on the views of Hughlings Jackson and Sherrington.

The hypothesis we have put forward in this section, to explain the phenomena of excessive facilitation, follows directly on the work of our predecessors. We hold that, so long as certain primary extensor reactions can be evoked from the lower extremities, the flexion reflex retains its double character. On the one hand it is a phase in change of posture and locomotion, and on the other a defensive movement of withdrawal. It does not matter how gravely motion, sensation and visceral control may be disturbed provided there is sufficient connection between the lower end of the spinal cord and the higher centres to maintain postural tone. So long as extension can be obtained as a primary reaction, energy does not overflow into visceral channels when moderate noxious stimuli are applied to the lower extremity, nor is it possible to evoke flexor spasms by allowing fluid to run into the bladder.

When, however, after shock has passed away, the lower end of the spinal cord regains its activity uncontrolled by any influence above the lesion, the only response is a nociceptive reflex. This takes the form of a vast outburst of motor energy not confined to the parts stimulated, overflowing into visceral channels, a profound shrinking away of the animal from harmful stimulation. Not only is the spread of this reflex activity greater than under normal conditions, but the receptive field

from which it can be evoked is unlimited below the lesion in favourable cases. This is the "mass-reflex," and we have attempted to show that in it is revealed a primitive method of response which cannot occur under normal conditions of higher neural control. All traces of such primitive reaction have not been eliminated from the normal nervous system, because withdrawal of the limbs and trunk with evacuation of bladder and rectum may still occur under violent effective stimuli as with the emotion of fear. But the synaptic resistance against such an occurrence must be extremely high in man.

It is an essential condition for the development of the mass-reflex in its complete form with visceral facilitation that the reflexes should to a great extent have lost their local sign. But so long as flexion can be evoked by scratching the sole of the foot and extension by stimulating the thigh, it is obvious that the site of the stimulus still determines the specific character of the reflex response. Now we have shown that the absence of sensation does not of necessity destroy this local signature; it is obvious that afferent impulses must reach the spinal cord marked by some characteristic indication of their place of origin, but it is in no way necessary that they should affect consciousness. In the same way a total absence of voluntary movement does not necessarily lead to a massive response and visceral facilitation. In order that this mode of reaction may appear the mechanism for postural co-ordination of the trunk and limbs should have undergone such gross injury that no impulses can pass across the damaged region.

But if these proprio-spinal paths have been destroyed, or their functions abolished, the mass-reflex may appear in its complete form even though some sensation and voluntary movement are still present below the level of the lesion. Should this form of response follow stimulation of one lower extremity and not of the other, facilitation of the detrusor activity of the bladder may be evoked from the former limb only; in this case the overflow of reflex energy on to the visceral system appears to be independent of the relative condition of voluntary power in the two lower extremities [cf. Case No. 8].

In this discussion we have not yet mentioned the large body of French research on the nature of the reflexes. For our attitude can only be understood clearly by the close study of the development of English thought and particularly of Sherrington's conceptions as set forth in the "Integrative Action of the Nervous System." We cannot, however, close this paper without showing how we stand in relation to the work of the French authorities.

In 1898 Babinski described the "phénomène des orteils" or, as it is usually called, the "extensor response." This he considered to be a thing apart from limb flexion, which he called a movement of defence. The nature of the "extensor response" was wrapped in mystery but it was of the greatest diagnostic value as a sign of pyramidal affection.

Marie and Foix [6], on the other hand, insisted that when the spinal cord was set free from control three groups of reflexes made their appearance as the direct expression of spinal automatism. These are: (1) the "phénomène des raccourcisseurs" [flexors]; (2) the "phénomène des allongeurs [extensors]; and (3) the "reflexe d'allongement croisé." They pointed out that the Babinski reflex of upward movement of the toes was a part of the flexor phenomenon and had no connection with extension except by a confusion of anatomical nomenclature. They say: "Cette activité propre de la moelle . . . constitue l'automatisme médullaire, automatisme dont l'importance s'exagère dès que la moelle est 'libérée' de l'action des centres encéphaliques. . . . Aussi losqu'une lésion sectionne plus ou moins complètement la continuité des neurones qui retient les centres encéphaliques aux centres médullaires, on assiste à la *libération de la moelle* et on la voit développer une activité propre demeurée latente chez le sujet normal . . . le terme *automatisme médullaire* exprime l'ensemble des mouvements co-ordonnés dont la moelle isolée est susceptible. . . ." [5].

Now Sherrington had shown that, after shock had passed away, the spinal dog could stand to a certain extent; but the posture assumed was unstable. In the same way some primary extensor manifestations could be obtained, under favourable conditions, but there was nothing comparable to the extensor rigidity of the decerebrate animal. This however applies to the dog; the spinal monkey cannot stand and exhibits little or no extensor activity.

The higher development of man has evidently robbed the spinal cord of still more of the functions with which it was originally endowed. Under the most favourable conditions we have discovered a vigorous activity in the divided spinal cord. But all postural activity has disappeared and does not return; "spinal man" cannot stand, and shows no primary extensor activity.

Evidently Marie and Foix were dealing with a different group of cases from those on which we have based the main argument in this paper. They described many of the phenomena which occur

when the spinal cord has been grossly injured. But they attribute all these conditions, flexor or extensor, "mass-reflex" or response endowed with local signature, to automatic action of the spinal cord.

We, however, believe that so long as local reflex signature is not destroyed, and so long as primary postural reflexes can be obtained, the lower end of the spinal cord has not been liberated from control of the parts above the lesion. All voluntary motion and sensation may be destroyed and bladder and rectum may be acting automatically, but excessive facilitation and the overflow of reflex energy into visceral channels will be inhibited. Thus, although we in no way underestimate the value of these researches of Marie and Foix, the very existence of many of the phenomena in which they are interested precludes the appearance of those which form the theme of this paper.

Conclusions.

The Automatic Bladder.

(1) When the spinal cord has been completely divided, the bladder may begin to expel its contents automatically as early as twenty-five days after the injury, under favourable conditions.

In unfavourable cases, where the patient suffers from chronic septicæmia, due to a bed-sore, grave cystitis or pyelitis, automatic micturition may never become established, however long the patient survives the injury.

(2) If a catheter is passed after automatic but involuntary micturition has become established, and fluid is allowed to run into the bladder under the least possible pressure, it will be expelled after a certain volume has entered. This volume varies between about 100 and 600 c.c.

We wish, however, to insist that this expulsion of fluid through a catheter, owing to the contraction of the muscles of the bladder-wall, can be evoked at a time when the patient is unable to micturate automatically, that is to say during the period of complete retention. This retention is due to spasmodic contraction of the sphincter mechanism, which does not relax although the muscular wall of the bladder is capable of vigorous contraction.

Later, however, under favourable general conditions, true automatic micturition may become established even though the spinal cord is completely divided. When the contents of the bladder reach a certain

amount, its muscular wall contracts, the sphincter relaxes and urine is passed involuntarily.

(3) The form assumed by the activity of such an automatic bladder is entirely independent of the site of the lesion in the spinal cord.

(4) If the spinal cord is gravely injured and even if it is completely divided anywhere above the lumbar region, automatic evacuation and the complete act of micturition may be facilitated by the most various afferent impulses passing into the lower portion of the spinal cord.

When the sole of the foot, the thigh or the abdomen is scratched, a flexor spasm may be evoked. If this is so, the bladder may empty itself when its contents scarcely reach one half of the amount otherwise necessary to produce a contraction of the muscular wall.

(5) After destruction of the lower lumbar and sacral roots, the bladder may act automatically in an identical manner, except that it can no longer be influenced reflexly by any afferent impulses.

(6) When the lesion is confined to the lower end of the spinal cord or to the lower lumbar and sacral nerve roots, the patient may be conscious of tension within his bladder, may recognize the occurrence of contractions in its muscular wall, and may experience that pleasure which normally accompanies evacuation. But these sensations have no effect on the automatic activity of the bladder.

(7) When the bladder is acting automatically, deep breathing may cause the muscular wall to expel its contents before they have reached sufficient volume to be otherwise an adequate stimulus.

In the same way, pressure on the abdominal wall not only tends to expel the contents of the bladder mechanically, but also acts as a stimulus to otherwise premature evacuation.

(8) When washing out a bladder, in order to treat the cystitis, so frequently present in patients with spinal lesions, it is most important to avoid exercising undue tension on the bladder-wall. The fluid should be allowed to run in under the smallest possible pressure; the vessel containing the wash must not be raised, as is so commonly done, some feet above the bed, nor must the bladder be injected from a syringe. Such methods are positively harmful; for the tone and contractile capacity of the vesical musculature are overcome by such pressure, and the power of spontaneous evacuation thereby diminished. In every case where an automatic bladder is to be washed out for therapeutic purposes, the volume of fluid should be determined at which evacuation occurs, and the bladder should always be allowed to empty itself, as far as possible, in response to endovesical stimuli.

Excessive Sweating.

(9) In most cases of hyperidrosis, associated with gross lesions of the spinal cord, the outburst of sweating represents the activity of the nervous system *below* the lesion.

Thus, when the injury is situated in the lower cervical segments, the whole head and neck may be covered with sweat, because all the fibres which produce sweating leave the spinal cord in the thoracico-lumbar region. A lesion at the level of the third thoracic segment caused excessive sweating over both arms and over the trunk below the second rib; in a case where the injury lay in the sixth thoracic segment, hyperidrosis extended from the fifth rib downwards with some moisture of the palms of the hands. When the injury was situated at the ninth thoracic segment, the hyperidrosis corresponded almost exactly with the extent of the analgesia, whilst below this segment the area occupied by the sweating was smaller than that of the loss of sensation. In some cases this sweating may be unilateral.

(10) In favourable cases paroxysmal sweating can be excited by almost any stimulus which sends afferent impulses into the spinal cord below the lesion. For instance:—

(*a*) Scratching the sole of the foot, the abdomen or any part below the level of the lesion, provided it evokes flexor spasms.

(*b*) Injection of fluid into the bladder. Inability to pass urine when the bladder is full is one of the most frequent causes of "spontaneous" hyperidrosis in these cases; sweating ceases when a catheter is passed and the endo-vesical pressure is relieved.

(*c*) Injection of fluid into the lower bowel, as when administering an enema.

Reflex Activity of the Spinal Cord below the Lesion.

(11) It is evident, therefore, that under certain conditions the spinal cord below the level of the lesion may show signs of diffuse reflex activity. Scratching the sole of the foot may not only evoke a flexor spasm, but may cause premature evacuation of the bladder and an outburst of excessive sweating. This we have spoken of as a "mass-reflex."

When the spinal cord has assumed this form of activity, any stimulus giving rise to impulses endowed with affective tone will evoke this diffuse reaction. Not only can evacuation of the bladder and rectum be facilitated by scratching the sole of the foot, but injecting fluid into either of these organs may evoke characteristic flexor spasms.

(12) When the spinal cord reacts with this massive response, it is obvious that the reflexes have, to a great extent, lost their local signature. Not only is the answer the same when diverse parts, such as the sole of the foot, the bladder or the rectum are stimulated, but it matters little what part of the skin is scratched provided it is supplied by the spinal cord below the lesion. Scratching the abdomen or the sole of the foot may evoke the same reflex response.

(13) Should the local sign of the reflexes be retained to such a degree that primary extension can be evoked by scratching the thigh, though flexion is caused by nociceptive stimuli to the sole of the foot, this diffuse and massive response fails to appear. Evacuation of the bladder cannot be facilitated from the limb which yields a primary extensor response to stimulation of the thigh. We believe that the presence of reflex stepping is another indication that the reflexes have not entirely lost their usual local signature.

(14) All voluntary movement, sensation and visceral control may be lost below the level of the lesion, and yet excessive facilitation may not be present. This may be due to the following causes:—

(*a*) The patient may suffer from continuous septicæmia or toxic absorption, due to a foul bed-sore, cystitis, or pyelitis. The lower end of the spinal cord has no chance to recover from the first period of shock due to the injury, and reflex activity does not return to any material extent, however long the patient may live.

(*b*) In spite of the severity of the injury, the centres above the level of the lesion may still exercise sufficient control to prevent this widespread reflex activity. The severity of the injury has not been sufficiently great to prevent the neural mechanism for postural adaptation from influencing the parts below the lesion, though voluntary motion, sensation, and visceral control may be lost. This maintenance of postural activity is shown, in man, by the existence of primary extensor reactions and the presence of local signature in the reflexes which can be obtained from parts below the lesion.

SHORT ACCOUNT OF ILLUSTRATIVE CASES.[1]

Case 1.—*Total division of the spinal cord at the level of the sixth dorsal segment. Complete loss of voluntary power and sensation below this level. Automatic micturition. Facilitation of detrusor activity of the bladder by any reflex activity below the level of the lesion. Paroxysmal sweating, which could be evoked by injecting the bladder or rectum, or by producing flexor spasms from parts below the lesion.*

Lieutenant M., aged 28, was wounded by a shrapnel bullet in the spine on August 6, 1916.

On August 16 he was admitted to the Empire Hospital, under the care of Dr. Collier. Next day (eleven days after injury) his condition was as follows:—

Motion.—There was total flaccid paralysis below the level of the sixth rib. The muscles were not wasted. There were no involuntary movements of the lower extremities.

Reflexes.—Arm-jerks were brisk and equal. All reflexes both superficial and deep were absent below the lesion.

Sensation.—Complete loss below the level of the sixth rib. Above this a narrow area of over-reaction could be mapped out occupying mainly the fourth interspace. Vibrations of a tuning-fork could not be appreciated above the level of the ninth rib.

Sphincters.—There was complete retention of urine. A catheter was passed every six hours, and the bladder was washed out with a solution of eusol, 1 in 16,000, night and morning. The anal sphincter was tonic.

Sweating was at this time absent over the trunk and lower extremities.

On August 28, 1916 (twenty-two days after the injury) *motion* and *sensation* were in a similar condition.

Reflexes.—Knee- and ankle-jerks were absent. Abdominal reflexes absent. For the first time on this date upward movement of the toes was noticed on scratching the sole of the foot. Hamstring contraction had not been obtained previously on plantar stimulation; but with the first appearance of this upward movement of the toes the hamstrings could be felt to tighten and contraction also appeared in the anterior tibial group of muscles. The receptive field for this reflex was limited, at this stage, to the soles of the feet and the threshold was lowest on the outer side. No crossed response of any kind could be obtained.

Sphincters.—Retention of urine was no longer complete. A small quantity of urine was passed reflexly on one or two occasions.

Sweating.—He had begun to sweat on the left side of the head and neck, left arm, and down to the level of the third interspace. The skin of the right

[1] Nos. 1, 2 and 3 correspond to the same numbers in Riddoch's paper. No. 4 in this paper corresponds to his No. 6.

arm, right half of the face, and all the trunk below the level of the fifth rib was dry.

By the twenty-fifth day after the injury slight periodic movements were noticed in both legs, but not at the same time; these consisted of upward movements of the great toes, tightening of the tibialis anticus and of the hamstring tendons. On tapping the right patellar tendon contraction of the quadriceps muscle, chiefly in the vasti, occurred, and the slack tendon was seen to tighten momentarily. Periodic micturition was more frequent and more urine was voided at a time.

On September 8 (thiry-three days after the injury) a shrapnel bullet was removed from the body of the sixth dorsal vertebra. Opposite the bodies of the fifth and sixth dorsal vertebræ the cord was completely divided and the ends were separated by about 2·5 cm.

When he recovered from the immediate effects of the operation he rapidly assumed a condition which was, in the main, constant. This was interrupted in the early part of 1917 by an attack of cystitis and pyelitis, which led to some weeks of fever. But apart from this period his condition may be summarized as follows:—

Motion.

All voluntary motion was completely absent below the level of the sixth rib. But involuntary movements occurred with great frequency and were very active. All such spasms were invariably of the flexor type: the great toe moved upwards, the foot was dorsiflexed at the ankle, and both knee and hip flexed vigorously. At the same time the thigh became adducted and the rectus abdominis of the same half of the body fell into spasm. In some cases the involuntary movement might begin in the muscles of the abdominal wall and spread rapidly to the lower extremity. Sometimes the legs flexed alternately; more often, however, two or three flexion movements of one leg occurred in quick succession before the other leg moved. On one day the right leg might "jump" more often than the left, and on the next the left be more active than the right.

From the forty-fifth day after the injury the extensors of the opposite limb to the one in flexor spasm could be felt to contract; but at first this movement did not produce any effect upon the position of the limb. By the 259th day, however, each flexor spasm in one leg was accompanied by definite movement of the quadriceps cruris and calf muscles of the other, so that the limb would shoot out extended in front of him as he sat in his chair. The flexors showed no signs of wasting, but the extensors were certainly smaller than normal.

When the lower extremities were not in motion the tone of the physiological flexors was below normal, but that of the extensors was relatively much less developed. During contraction, however, the tone of the flexors was greatly raised, whilst the tone of the extensors of the limb was greatly diminished. When the extensors were contracting the converse was true: a

flexion reflex was induced and the crossed extensors contracted; their tone was increased, but it was never so great as that of the contracting flexors.

Reflexes.

Knee- and ankle-jerks became greatly exaggerated shortly after their return. No definite ankle clonus appeared, but on thrusting up the foot a few brief jerks appeared. It was, however, difficult to examine for ankle clonus satisfactorily owing to the flexor spasm, so easily evoked by touching or holding the foot. This flexion reflex could be obtained by stimulating any part of the lower extremities. Its reflexogenous area extended from the abdomen to the foot, although the threshold was somewhat lower on the sole than elsewhere. The most effective stimulus was one which would have possessed some affective element, had the parts been sensitive; scratching the abdomen or lower extremity and grasping the foot or muscles of the thigh would at once evoke spasmodic flexion.

By no manipulation could we produce a primary extension in the stimulated limb.

Stimulation of the glans penis, the external genitalia, the skin of the perineum, and for a short distance down the inner aspect of the thighs produced a strong flexion reflex with contraction of the abdominal rectus and slow drawing up of the testicles. This is a remarkable contrast to the extension reflex so commonly obtained in less complete lesions of the spinal cord.

When the outer part of the abdomen was scratched a slow local contraction might occur in the external oblique, following the direction of the fibres of this muscle upwards and outwards. This response was delayed and was never associated with a crossed movement of the abdominal wall.

But when the abdomen was briskly scratched over a wider area, or when the parts over the rectus were stimulated, a vigorous contraction of one or both recti associated with a full flexor spasm of the lower extremity including upward movement of the toes.

Sensation.

The loss of sensation to touch, pain and temperature remained complete below about the sixth rib. Vibration of a tuning-fork was not appreciated below the level of the ninth rib. Deep pressure with the hand produced a vague discomfort over the epigastrium, and he seemed to be aware of flatulent distension of his stomach.

He had no sensation of the movements of his lower extremities and usually thought of them as flexed to a varying amount. Passive movements were entirely unappreciated.

He had no abdominal sensations except from the epigastric region after food. He could not recognize distension of his bladder and had no desire to pass urine, or relief when the bladder was emptied.

Observations on the Bladder.

On January 11 (158 days after the injury) the following observations were made:—

Two minutes before the catheter was inserted he passed automatically 110 c.c. of urine as soon as the swab with antiseptic fluid was placed on the glans penis. The catheter drew off 340 c.c. of urine.

On allowing a solution of eusol, 1 in 16,000, to run into the bladder he evacuated his bladder at 650 c.c., passing in all 610 c.c. No more could be recovered by pressure. On a second occasion he evacuated at 600 c.c., passing 595 c.c. Nothing was recovered by pressure. On a third experiment he evacuated at just short of 600 c.c., passing 590 c.c.

Throughout these observations the column of fluid showed oscillations which, on asking him to stop breathing, proved to be respiratory. After about 400 to 500 c.c. of fluid had entered the bladder a bigger oscillation began, which culminated in the backflow. About 300 c.c. was evacuated at once; then came a pause followed by a further passage of 200 c.c., then another pause, and so on.

Throughout these manipulations he was unconscious of fluid distending the bladder, of desire to make water or of the passage of fluid.

The urine was acid and free from pus or albumin.

On April 22 (259 days after the injury) the following series of observations was made: During the month of February he had suffered from an attack of pyrexia with nausea and occasional vomiting, probably due to an attack of cystitis, with some infection of the pelvis of the kidney. This passed away and he returned to his previous condition of robust general health.

On passing a catheter 420 c.c. of urine were drawn off. A solution of eusol, 1 in 16,000, was allowed to run into the bladder and evacuation occurred at 325 c.c.; he passed 300 c.c. On rubbing the glans penis 10 c.c. came away and an additional 10 c.c. were recovered by pressure over the abdomen. Fluid was again allowed to run in and evacuation occurred at 195 c.c., just after he had taken a long breath. He passed 190 c.c.; 5 c.c. was recovered by rubbing the glans penis, and 5 c.c. by pressure on the hypogastric region. At another experiment he emptied his bladder at 295 c.c., passing 300 c.c.; a further 5 c.c. was obtained by rubbing the penis, and nothing more by pressure.

It is obvious from a comparison of these observations with those made in January that the capacity of the bladder had diminished. This was probably due to the febrile attack through which he had recently passed. As before, respiratory oscillations were seen in the column of fluid in the tube, which were distinct from the bigger oscillations that immediately preceded the backflow.

When the catheter was passed along the urethra, considerable resistance was offered to its passage as the point came against the sphincter. With gentle and steady pressure this resistance yielded and the catheter entered the bladder. It was then held tightly by the sphincter, as shown by the force required to withdraw it.

On April 29 (266 days after the injury) another series of measurements was carried out. When the penis was swabbed preparatory to passing the catheter 85 c.c. of urine were voided, and the catheter then drew off a further 200 c.c. No more urine could be recovered by rubbing the glans or by pressure on the abdomen. Dilute eusol solution was allowed to run into the bladder and backflow began at 180 c.c.; he passed 180 c.c. and nothing more was recovered by rubbing the glans or by pressure. Again the fluid was run in and evacuation begun at 210 c.c.; he passed the full amount and nothing was recovered on pressure. A third observation was made and the fluid returned at 240 c.c.; the whole 240 c.c. were passed and nothing recovered on pressure.

The next observation was carried out as follows: 100 c.c. were allowed to run into the bladder and a flexion reflex was induced by scratching the left sole. A few bubbles came up through the fluid in the tube and the column remained stationary for a few seconds, but no backflow occurred. A similar result followed scratching the right sole. 10 c.c. of fluid were then added, making in all 110 c.c. On scratching the right sole, strong flexion occurred and the bladder evacuated 105 c.c. of fluid. This experiment was repeated and 115 c.c. allowed to run into the bladder and flexion was induced by scratching the sole: the column of fluid remained stationary for a time, but no backflow occurred. 10 c.c. were added, making in all 125 c.c., and the production of a flexor spasm was at once accompanied by evacuation of the bladder; 130 c.c. were passed.

These manipulations produced a profuse outburst of sweating over the trunk and limbs below the level of the fourth rib.

Another series of observations was made on June 27 (325 days after the injury). A catheter was passed and 190 c.c. of urine drawn off. Fluid was then allowed to run in from the burette in the usual way and evacuation occurred at 425 c.c.: he passed 420 c.c. and nothing was recovered by pressure. Fluid was again run into the bladder and evacuation occurred at 420 c.c.; he passed the whole amount and nothing was recovered by pressure.

The patient was now asked to breathe deeply from time to time during the entry of fluid into his bladder. He evacuated when 58 c.c. only had entered, passing 60 c.c. in all. He was asked to repeat this procedure, and this time he returned the fluid when 25 c.c. only had entered, passing 30 c.c. in all.

When fluid was run in and flexion reflexes were evoked rhythmically from the right foot, every spasm caused hesitation in the movement of the column after 50 c.c. had entered the bladder; but evacuation did not occur until 160 c.c. had entered. He then passed the whole amount.

Thus it was obvious that the adequate stimulus to the muscular wall of the bladder was a volume of about 420 c.c. of fluid. But deep breathing so greatly facilitated evacuation that contraction occurred when from 30 to 60 c.c. only had entered the bladder. Flexor spasms evoked from the sole of the foot caused evacuation at 160 c.c. We were therefore anxious to ascertain if such stimuli could facilitate automatic micturition when the catheter was removed and a

measured quantity of fluid left in the bladder. We knew that the patient was able to induce micturition by scratching his thigh if he had not passed urine for several hours. This was, however, technically an extremely difficult experiment, for when 200 c.c. were left in the bladder and the catheter removed neither deep breathing nor scratching the sole of the foot led to automatic micturition. When 350 c.c. was left in the bladder the very slight stimulus of removing the catheter was usually sufficient to cause evacuation of the whole amount. But a few days before we had succeeded in passing 400 c.c. into the bladder and removing the catheter without provoking evacuation; then scratching the thigh caused a flexion reflex and 80 c.c. were passed in a fine strong stream. Thus we were able to show, in spite of the technical difficulties of the experiment, that a volume of fluid incapable of evoking the act of micturition could be made an adequate stimulus on calling up a "mass-reflex" by scratching the thigh. This exactly corresponded with the patient's practical experience. Thus before he got up in the morning he would ask for the bottle, scratch himself and empty his bladder. Subsequent manipulations, such as dressing himself, could then be carried out without the discomfort of the involuntary passage of urine.

Sweating.

At first, as has been mentioned above, the parts below the lesion were dry, but he sweated over the left side of the head and neck, left arm, and down to the level of the third interspace. This steadily decreased as the weather grew cooler, and on September 20 (forty-five days after the injury) the parts below the level of the lesion were noticed to be damp.

By October 6 (61st day) sweating over the face, neck and shoulder had ceased, but sweating below the level of the lesion was definite; the palms of the hands, the trunk below the fourth interspace and the legs were distinctly moist. By November 4 (90th day) this had become a definite hyperidrosis and all abnormal sweating had ceased over parts that received their nerve supply from the spinal cord above the lesion.

By December 28 (144th day) it was noticed that the hyperidrosis was associated with the passage of a catheter and the subsequent manipulations for washing out the bladder. Administration of an enema was also found to evoke an outburst of sweating over parts below the lesion.

During the month of February, 1917, he passed through a febrile attack due to urinary infection, and during this time the skin of the whole of the face, neck, body and limbs were damp in the normal manner, and during the night he sweated freely, as is so commonly the case with pyrexia of this character. But he always sweated more profusely from the palms of the hands and from the skin below the level of the lesion than from the rest of the body.

With the disappearance of the fever the general sweating ceased, but the local reaction, representing the parts supplied from below the lesion, sweated more profusely than ever.

Thus on April 22 (259 days after the injury) the following note was made: (*a*) In extent the sweating occupied the palms of the hands, the skin of the trunk below the fourth rib, and the legs. The arms have never been noticed to participate in this excessive sweating. (*b*) Adequate stimuli for bringing on sweating were: (1) Spasms of the legs; the repeated induction of flexion reflexes was accompanied by increased sweating over the usual area. (2) An enema, administered whilst lying on his side, always evoked sweating. (3) Catheterization. (4) Change of temperature; thus, when he was lifted out of his bath sweat poured from the palms, lower half of the chest, abdomen, and legs. He also began to sweat profusely shortly after he was put to bed; he sweated less when up in a chair. It was as profuse as ever and the distribution had not changed. The head, neck, shoulders, and arms, except the hands, were always perfectly dry. No change in the pulse or pupils had ever been noticed to accompany the hyperidrosis.

Before we began our observations on April 29 (266th day) the skin of the body was examined and found to be perfectly dry. The various experiments on the activity of the bladder occupied three-quarters of an hour; at the end of that time the skin was again examined. The legs up to the thighs were pouring sweat and the skin of the trunk below the fourth rib, together with the palms, was distinctly damp. The rest of the surface was dry as before. He declared he could usually tell when sweating was about to begin by the onset of "drumming in the head or a feeling of fatheadedness."

Case 2.—*Complete anatomical division of the spinal cord at the level of the fourth thoracic segment. Total loss of voluntary movement and sensation up to the level of the nipples. All involuntary movements of the flexor type. Flexor "mass-reflex" evoked by nociceptive stimulation of abdomen or lower extremities. Automatic micturition. Expulsion of contents of the bladder through a catheter at from* 250 *to* 290 *c.c. Facilitation on producing a "mass-reflex" led to evacuation at* 150 *c.c. Paroxysmal sweating, greatly increased by filling the bladder with fluid.*

Private H., aged 24, was wounded in France on July 21, 1916, and admitted in August to King George Hospital, under the care of Dr. Buzzard.

On September 11 (fifty-two days after the injury) a shrapnel bullet was removed from the theca. This had completely divided the spinal cord at the level of the 3rd and 4th dorsal vertebræ, and there was a gap of $\frac{3}{4}$ in. (2 cm.) between the two ends.

A full account of this patient will be found in Riddoch's paper [7], and we shall therefore confine this account to the observations made on February 24, 1917 (218 days after the injury), when we examined him together. His condition was then as follows:—

Motion.—There was total paralysis of voluntary movement below the level of the nipples. When not in spasm, the legs lay on the bed a little flexed at

the knee and at the hip. The feet pointed somewhat downwards, but the left great toe looked somewhat upwards.

All involuntary movements, evoked by stimulation, even by removing the bedclothes, were flexions. There was no evidence of a crossed response accompanying the flexor spasms.

Reflexes.—The arm-jerks were brisk and normal. Knee- and ankle-jerks were greatly exaggerated but no definite ankle clonus was obtained.

On scratching the sole of the foot a characteristic flexor spasm was evoked with an upward movement of the great toe and splaying of the four outer toes. This reflex could also be evoked by scratching the inner aspect of the knee or the groin, more strongly from the left than from the right lower extremity. This response was produced most easily by pricking and grasping the sole or by squeezing the thigh. There was occasionally distinct bilateral flexion but no crossed extensor movement.

On dragging a pin across the abdomen it was possible to evoke a localized undulation running from the rectus sheath outwards and upwards to the ribs. This movement was somewhat vermicular and slow to appear; it was not part of a "mass-reflex," but seemed to follow the line of the abdominal muscles at the level of the stimulus. Associated with this reflex there was no movement of the toe or flexion at the knee.

Not infrequently, however, the abdominal reflex was of a different character. The rectus of the stimulated half contracted, and that side of the abdomen was pulled in and rendered concave as a whole. Whenever this form of reflex was evoked the great toe tended to move upwards and there was a complete flexor reflex of the leg. The occurrence of this form of response on one side might be accompanied by a contraction of the rectus and abdominal wall on the other half of the abdomen.

Sensation.—There was total loss of sensation below a line at the level of the nipples.

Bladder.—He was passing all his urine involuntarily and unconsciously. The following observations were made: A catheter was passed and 175 c.c. were drawn off. The burette was attached directly to the mouth of the catheter and normal saline solution was allowed to run into the bladder. At 250 c.c. evacuation occurred and he passed 135 c.c.; a further 130 c.c. were passed after pressing on the abdomen.

The same procedure was repeated and he evacuated 290 c.c., passing 175 cc. The glans penis was then rubbed with a swab and he voided another 57 c.c. Pressure over the bladder caused the passage of another 70 c.c.

On the next occasion he evacuated at 250 c.c., passing 140 c.c. This flow was started by accidentally rubbing the glans penis. Stimulation of the sole caused the evacuation of another 50 c.c., and pressure 90 c.c. Again 100 c.c. were allowed to flow into the bladder. Stimulation of the glans caused no evacuation; but when the amount had been made up to 150 c.c. and the penis was stroked he passed 30 c.c. Pressure evacuated another 100 c.c. 150 c.c. were then allowed to flow into the bladder and the

flexion reflex evoked by scratching the sole of the foot. The bladder was immediately emptied.

Sweating.—We were told that he sweated profusely from the second rib downwards, for a varying distance, to about the ensiform level with a maximum over the upper thoracic region. On the occasion of these observations this was a strictly accurate description of the condition in which we found him. When we started to fill his bladder he was slighly moist over this area, but as soon as his bladder began to expel its contents automatically he sweated profusely. The head and neck remained dry, but from the clavicles downwards all over the arms and chest he became wringing wet. The sweating extended to the groins and the thighs, soles and back of the legs, but not so profusely as over the arms, chest and abdomen. The pupils did not dilate and the face was not flushed.

Case 3.—*Complete division of the spinal cord at the level of the fourth thoracic segment. Total loss of voluntary motion and sensation below the level of the fifth rib. Gradual development of increased tendon reflexes but no definite ankle clonus. Characteristic "mass-reflex" obtained from the abdomen and lower extremities associated with facilitation of the detrusor activity of the bladder wall.*

Captain F., aged 29, was wounded on April 6, 1917, by a shrapnel bullet in the back.

He was admitted to the Empire Hospital on April 10, 1917, under the care of Dr. Buzzard.

On April 13, 1917 (seven days after the injury) his condition was as follows:—

Motion.—Total flaccid paralysis below the fifth rib. No involuntary movements. The legs were not wasted.

Reflexes.—Arm-jerks were brisk and equal. Knee- and ankle-jerks were absent. A bulbo-cavernous reflex could be obtained by pricking either side of the glans penis.

On scratching the sole a downward movement of the toes occurred with no palpable tightening of the hamstring tendons.

Scratching the skin of the abdomen over the external oblique caused a localized movement of this muscle. A sharper scratch applied over a larger area evoked a massive response in all the muscles of the same half of the abdomen, including the rectus.

Sensation.—There was total loss of sensibility below the level of the fifth rib, with a broad area of over-reaction to painful stimuli extending from the second thoracic segmental area on the arms to the upper level of the loss of sensation.

Sphincters.—Complete retention of urine and fæces.

Vasomotor and trophic.—No excessive sweating. There was no bed-sore.

On April 20 (fourteen days after the injury) laminectomy was performed, and a shrapnel bullet was removed from within the dura at the level of the

lamina of the fourth dorsal vertebra, which was fractured. The spinal cord was completely divided and the two ends were separated by a gap of 1 cm.

On May 5 (twenty-nine days after the injury) his condition was as follows:—

Motion.—Involuntary movements were of rare occurrence, but consisted of upward movement of the toes with contraction of the inner hamstrings; this was not, however, sufficient to flex the knee. The legs were not appreciably wasted, but the tone of both flexors and extensors was below normal. The abdominal recti frequently fell into spasm without any corresponding movement of the lower extremities.

Reflexes.—Tendon jerks: Some contraction of the left quadriceps could be evoked by tapping the patellar tendon twenty-one days after the injury, but it was not sufficient to move the leg. In the same way the left ankle-jerk could be obtained but the right was absent. On the twenty-third day both knee- and ankle-jerks were obviously present. On the twenty-ninth day three or four brief clonic movements of the calf muscles were obtained when the foot was jerked up sharply; there was no true ankle clonus.

Plantar reflex: The threshold value was high even on the sole, but scratching, pinching and squeezing the foot evoked upward movements of the toes, slight dorsiflexion at the ankle, flexion at the knee and hip and adduction of the thigh. There was no active after-extension and no crossed flexor or extensor movement could be observed. The receptive field for this reflex extended from the sole of the foot to just below the knee.

Abdominal reflex: A pin-prick over the external oblique still resulted in a delayed local contraction. More vigorous stimulation, especially near the middle line, led to widespread contraction of the abdominal muscles which was sometimes bilateral. Upward movement of the toes and flexion at the knees sometimes accompanied this massive response evoked from the abdomen.

Sensation was lost as before.

Bladder.—To-day (thirty days after the injury), the patient passed some urine, when his penis was swabbed before passing the catheter. This was followed during the night by active involuntary micturition.

A solution of 1 in 16,000 eusol was allowed to run slowly into the bladder and he evacuated at 365 c.c., passing in all 320 c.c. On pressing the abdomen 80 c.c. more of fluid were voided. Two days later, on May 7 (thirty-two days after the injury), these observations were continued. On passing a catheter 230 c.c. of urine were drawn off. When fluid was allowed to run in slowly he evacuated at 350 c.c., passing 350 c.c.; pressure led to the voiding of 5 c.c. only. At a second observation he evacuated at 375 c.c., passing 370 c.c.; pressure brought away 15 c.c.

Fluid was then poured in to the amount of 200 c.c., and the flexion reflex evoked by scratching the sole of the right foot. He immediately evacuated 150 c.c., and 50 c.c. in addition were recovered by pressure. Fluid to the amount of 100 c.c. was run into the bladder, and a flexion reflex evoked by squeezing the right foot. Fluid came back into the burette to a small amount and then remained stationary; after a few seconds the burette began again to empty

itself into the bladder. At 150 c.c. the flexion reflex was again evoked and again the fluid rose in the tube, remained stationary for a time, and then again entered the bladder. The impulse was not strong enough to cause complete evacuation even against this small pressure of fluid.

From this time onwards the involuntary flexor spasms increased, but we never saw any primary extensor movement. Any crossed movement which might occur was flexor, and there was no "extensor thrust." The tendon reflexes increased but no true ankle clonus was obtained. Stimulation of the abdomen or almost any part of the lower extremities would evoke a characteristic flexor spasm which caused premature evacuation of the bladder. The following observations were made on June 6 (sixty days after the injury) :—

He had passed no urine for four hours; on swabbing the penis no urine came away but the penis began to become erect. A catheter drew off 250 c.c. of urine. Sterile warm water was allowed to flow into the bladder, and at 300 c.c. he passed 305 c.c. Pressure led to the passage of a further 15 c.c., showing that he had passed some urine into the bladder during these manipulations. At a second observation he evacuated at 395 c.c., passing 390 c.c.; pressure brought away 5 c.c. only. Again fluid was allowed to run into the bladder and was passed at 380 c.c.; he voided the total amount, no fluid being recovered on pressure. Then 100 c.c. was run into the bladder and the sole stimulated by scratching, without result on the flow of fluid. At 165 c.c. the column of fluid began to hesitate with each flexor spasm and at 185 c.c. he evacuated. passing just under 190 c.c. On pressing the abdomen 4 c.c. came away. This experiment was repeated, and at 170 c.c. the column of fluid hesitated; evacuation occurred at 180, and the whole amount was passed. Fluid was now run into the bladder, and the patient was asked at each 10 c.c. to take a deep breath. At 60 c.c. the column moved up a little; at 80 c.c. evacuation occurred and the whole amount was passed. This experiment was repeated; at 60 c.c. the column again rose a little, and at 70 c.c. evacuation occurred with the passage of 75 c.c.

Case 4.—*Bullet wound of the chest and spine not completely dividing the spinal cord. Paralysis of motion and sensation below the sixth rib. Involuntary "steppage" movements. Crossed extension. Extensor thrust in the stimulated limb with bilateral extension reflexes. "Mass-reflex" absent. Automatic evacuation of bladder and rectum. No facilitation.*

Captain P.,[1] aged 30, was wounded by a machine-gun bullet on October 2, 1916. On October 14, 1916, he came under the care Dr. Batten at the Empire Hospital for Officers. A small entry wound was found 4 cm. to the right of the fourth dorsal spine, and an exit wound 7 cm. to the left on the same level. He was completely paralysed and had lost sensation below the sixth inter-

[1] This is No. 6 of Riddoch's series [7].

space. He was extremely ill with hæmothorax, and no full examination could be made until December 15 (seventy-four days after injury).

Motion.—There was complete paralysis below the level of the sixth interspace. The muscles were flabby and somewhat wasted. At intervals involuntary "steppage" movements occurred in both lower extremities; with flexion of one limb, extension occurred in the other, and *vice versa*.

Reflexes.—The knee-jerks were brisk and equal on the two sides. Ankle-jerks were less easily obtained and there was no ankle clonus.

On scratching, pinching, or squeezing either foot the toes moved upwards, dorsiflexion occurred at the ankle, with flexion at the knee and hip. This was invariably accompanied by crossed extension. The threshold value of the stimulus for this reflex was lowest over the outer part of the sole.

Scratching the skin of the abdominal wall caused a contraction of the muscles on the same side, but a bilateral response could be obtained by stimulating the middle line. No crossed reflex was obtained by scratching the flank.

Cremasteric reflexes were evoked by scratching the inner aspect of the thigh.

Sensation.—All sensation was lost below the level of the sixth rib.

Sphincters.—Bladder and rectum evacuated their contents automatically. Urine was voided about every two hours, and from 50 c.c. to 120 c.c. were expelled on each occasion. The urine was acid but contained albumin and some pus. Cultures grew Bacillus proteus profusely with a few colonies of B. coli.

On March 6, 1917 (155 days after the injury), his condition was as follows:—

Motion.—Total paralysis below the level of the sixth rib was present as before. Involuntary "steppage" movements were of frequent occurrence. There were no violent flexor spasms.

Reflexes.—Knee- and ankle-jerks were exaggerated and a poorly sustained ankle clonus was present. Scratching the sole produced an upward movement of the toes, dorsiflexion of the foot and flexion at knee and hip. At the same time the opposite leg became extended at the knee, the foot was plantar extended and the toes moved down. This crossed extension reflex was at once overcome and transformed with flexion by the application of a nociceptive stimulus to the sole of the extremity in which it had occurred. No crossed flexion reflex or bilateral flexion could be evoked by stimulating the perineum. The reflexogenous area for the flexion reflex extended from the sole, which was the focal area of the field, to the junction of the upper and middle third of the leg; the farther from the sole the higher because the threshold before the stimulus was adequate.

Light scratching of the thigh, groin and perineum evoked an extension reflex; the knee became extended and foot and toes moved downwards. From the lower part of the field the response was almost entirely in the stimulated limb, whilst from the groin it tended to become bilateral. From the perineum and external genitalia it was symmetrical on the two sides. Scratching the skin of the flank caused a localized contraction, and a similar strictly unilateral

reflex could be evoked from almost any part of the abdomen. Abdominal reflexes were not associated with any movement of the feet or legs.

Sphincters.—The rectum was acting automatically, and the sphincter ani was tonic. The bladder was emptying itself automatically, and catheterization had been stopped for three weeks. Six days later (161 days after the injury), the following observations were made: sterile warm water was allowed to run in, and at 170 c.c. the bladder contracted, evacuating 180 c.c. Fluid was again allowed to flow in and was returned at 154 c.c. to the amount of 140 c.c.; a further 42 c.c. was recovered by pressure, showing he had passed urine in the meanwhile into the bladder. Again the experiment was repeated and at 168 c.c. he evacuated the whole amount. Again 56 c.c. were introduced, and the penis pinched without result. In spite of repetition of this stimulus no facilitation occurred, and he voided at 168 c.c. to the amount of 140 c.c.; 28 c.c. were recovered by pressure.

A further set of observations were made on July 25 (296 days after the injury):—

Bladder.—On cleansing the glans no evacuation occurred, but erection was produced. A catheter drew off 280 c.c. of urine.

On passing fluid into the bladder it was held for some time at 280 c.c., and evacuation occurred at 295 c.c. He voided 290 c.c. By pressing deeply on the abdomen about 7 c.c. were recovered. On again passing fluid into the bladder a long delay occurred at 320 c.c., but evacuation did not occur till 350 c.c. had been reached. He passed 330 c.c., and 20 c.c. were recovered by pressure.

Fluid was now allowed to run in and the sole rhythmically scratched. Backflow occurred at 275 c.c., and he passed 270 c.c.; pressure recovered 10 c.c. This experiment was repeated, and he evacuated at 285 c.c., passing 280 c.c. Fluid was now passed in, and the patient was told to take a deep breath at intervals. He evacuated at 260 c.c., passing 230 c.c.; pressure recovered 30 c.c. These observations show that in this case there was no facilitation of reflex evacuation.

Rectum.—The sphincter ani was tonic and contracted as soon as the anal mucous membrane was touched with the finger. As it was allowed to rest in the canal the muscle held it with a slight steady tonic contraction. It was as if the sphincter had taken up a new posture to accommodate the contents of the canal. Like the bladder the rectum evacuated its contents automatically. Passive dribbling was unknown.

Case 5.—*Fracture dislocation of the fifth and sixth cervical vertebræ. Paralysis of the trunk and limbs below the level of the third rib and of most of the movements of both upper extremities. All involuntary movements were primary flexor spasms, in which the abdominal muscles frequently participated. There were no simultaneous bilateral extensor movements. Knee-jerks and ankle-jerks were brisk and ankle clonus could be obtained. There was no primary extensor thrust. A flexion reflex with extension of*

the wrist was obtained by scratching the palms. The abdominal reflexes were easily obtained. Scratching any part of the lower extremity evoked a flexion reflex with upgoing toes. There was complete loss of cutaneous sensibility below the level of the fifth cervical segment. Vibration was appreciated over the upper extremities but was lost on the trunk below the level of the third rib. The pupils dilated perfectly to shade. For many months there was complete retention of urine owing to contraction of the sphincter, probably due to injury during catheterization. During this time the bladder-wall could expel its contents actively through a catheter, when they reached an adequate volume. Automatic micturition was finally established. Profuse sweating over the head, neck, arms and trunk to the umbilicus, occasionally when severe reaching to the knees. This could be excited (1) *by flexor spasms,* (2) *by tension within the bladder,* (3) *on injecting fluid into the rectum.*

Air mechanic H., aged 23, fractured his spine in the cervical region about midday on September 14, 1916, owing to the crash of an aeroplane. He was admitted to the London Hospital on September 17, 1916, under the care of Dr. Head.

On admission he showed total flaccid paralysis of both upper extremities and of all the parts below. No reflexes could be obtained even in the arms, and sensation was lost up to the level of the lower border of the fourth cervical segment. There was complete retention of urine, and by the time he reached the London Hospital it contained thick, ropy pus, though acid in reaction. Several false passages had already been made by previous catheterization, which greatly added to our difficulties in relieving the tension in his bladder. He stated that a catheter was passed for the first time on the evening of September 14, and then not until midday on the 16th; it was passed once on the boat coming across during the night of the 16th to 17th. A radiograph in lateral view showed that the fifth cervical vertebra had gone forward on the 6th, which was extensively fractured. There was palpably some defect in the fifth and sixth cervical vertebræ, and, in consequence, the spine of the seventh cervical seemed to be unduly prominent, with an abnormal hollow above it.

On October 10, 1916 (twenty-six days after the injury), his condition was in the main unaltered. Both arms were still in a condition of complete flaccid paralysis, but distinct flexor spasms were now produced by uncovering his legs or by manipulations of his lower extremities. The right arm-jerk could just be obtained, but the left was absent. Both knee-jerks could be evoked without reinforcement and the ankle-jerks were present. The abdominal reflexes were obtained in all four segments, but the plantars showed an interesting condition. On scratching the sole of either foot with the legs lying passively extended on the bed in front of him, the great toe either remained stationary or moved slightly downwards; the remaining toes closed up and flexed, but at the same moment the inner hamstrings contracted and the knee was sharply flexed. If, however, the knee was slightly bent passively

and the sole was stroked with the point of a pin, the great toe moved definitely upwards at the moment when the hamstrings contracted.

The upper limit of the loss of sensation extended on the left side as before to the lower border of the fourth cervical segment, but on the right arm the whole of the fifth cervical segmental area was now sensitive to prick, heat and cold. The loss to touches with cotton wool corresponded almost exactly with the limits of the analgesia. Vibration was not appreciated on the trunk up to the level of the third rib in front and the spine of the scapula behind; over the left upper extremity it was lost to the elbow, over the right the loss of sensibility occupied the hand to the wrist, but was also defective over the right forearm.

Retention of urine was absolute, and it was necessary to draw off his urine three times in the twenty-four hours. But the bladder was certainly not atonic; for when 300 c.c. of the washing fluid had entered he ejected it through the catheter, passing 150 c.c. In the same way the rectum responded briskly to an enema.

About fifty days after the injury, or a little earlier, he began to be troubled with profuse sweating over the head, neck, arms and down to about the level of the third rib on the trunk. It gradually became so profuse that it poured from his face and neck and soaked the blankets on his bed. This hyperidrosis was peculiarly liable to be associated with a full bladder or with intestinal distension.

No material change occurred in his physical condition during the next ten months, but we gradually became more certain of the causes which underlay the outbursts of excessive sweating and were able to make repeated measured observations on the expulsive activity of his bladder. We shall therefore summarize his symptoms and physical signs under the headings of motion, reflexes, sensation, of observations on the bladder, intestinal and rectal states, and on excessive sweating.

Motion.—There has been no return of voluntary power to the trunk or lower limbs, but the motor condition improved somewhat in the upper extremities.

The arms usually lay slightly flexed at the elbow and three-quarters supinated; the wrist was strongly extended, the fingers somewhat flexed with the thumbs adducted and bent into the palm. On the right side he could make all movements at the shoulder and could flex the elbow, but could not extend it. Extension of the wrist was possible but not flexion. Beyond slight adduction of the thumb, all voluntary movement was lost in the parts below the wrist. In the left upper extremity the motor condition was identical except that slight flexion became possible in the fingers.

Respiration was purely diaphragmatic; the abdominal muscles were completely paralysed, but frequently fell into spasm.

No voluntary movement was possible in either lower extremity, but frequent involuntary contractions occurred in which the abdominal muscles participated.

Whenever the legs were manipulated—as, for instance, by flexing the knee passively with the hand under his thigh—the limb fell into flexor spasm accompanied by typical crossed extension in the opposite extremity; this, again, was followed by crossed flexion with extension in the limb originally stimulated by passive movement. Primary extension and simultaneous bilateral extensor spasms never occurred. There was no permanent rigidity.

Reflexes.—On scratching the palms of the hands a characteristic reflex could be evoked: the fingers and thumb became flexed, the wrist was extended but no movement occurred at the elbow or shoulder.

All the chief arm-jerks, except the triceps-jerk, were exaggerated

The abdominal reflexes were easily obtained from all parts and the rectus and oblique muscles participated in the movements evoked.

The knee-jerks consisted of a quick contraction with no tonic prolongation: the ankle-jerks were of the same character and ankle clonus could be obtained in both legs. No extensor thrust could be evoked at any time: the primary response to manipulation of the foot was always flexion at the knee.

On scratching the sole of the foot the first movement to appear, on the the smallest effective stimulation, was an upward movement of the great toe. A moderately strong stimulus evoked a full flexion reflex, consisting of flexion at the hip and knee, adduction of the thigh, dorsiflexion at the ankle and upward movement of the great toe: the other toes "fanned." No crossed reflex could be felt or seen.

A similar flexor spasm could be evoked by scratching or squeezing the thighs, and no extension, unilateral or bilateral, was ever seen as a primary response to such stimuli.

Sensation.—Sensibility to prick, heat and cold was abolished up to the level of the second rib, and over the greater part of both arms: the limits of the loss to light touch almost exactly corresponded to the analgesia, but were slightly less extensive, especially on the outer aspect of the arms.

Vibration was not appreciated up to the same level on the trunk, but was recognized over both upper extremities. All power of appreciating passive movement and posture was lost in the lower extremities.

Pupils, &c.—The pupils reacted perfectly to light and to accommodation, and dilated normally to shade. The palpebral fissures were equal and of normal size. There were no signs of sympathetic paralysis.

In the earlier days, when the paroxysms of sweating were extremely frequent and often very profuse, the pupils seemed to dilate in the attacks: but at this time he was greatly distressed by the headache and general discomfort with which they were associated. Later, when hyperidrosis did not occur unless it was excited by some definite manipulation, we could not satisfy ourselves that an induced attack of sweating was associated with definite enlargement of the pupils.

Observations on the bladder.—He was admitted with complete retention of urine and the catheter was passed every six hours. But it soon became evident that this rigid system was unsatisfactory. The bladder would fill to the same amount more rapidly sometimes than at others, and, as soon as its contents became an adequate stimulus, he would sweat profusely. This excessive sweating was accompanied by a feeling of fulness and discomfort in the head and made him feel weak and ill. So great was his distress, that he would clamour for the catheter to be passed more often; this was, however, difficult and inadvisable on account of the injuries to the urethra present on his admission to the hospital. Finally, 153 days after the injury (February 14, 1917), as the sphincter showed no sign of relaxing, a catheter was tied into the bladder. Whenever he complained of discomfort in the head or of excessive sweating, the mouth of the catheter was set free and urine was allowed to pass. This was a brilliant success, and in two days the sphincter had begun to relax, so that there was no difficulty in removing the gum-elastic catheter and replacing it by one of india-rubber. From this time onwards he began to improve in the most extraordinary manner; nausea, vomiting, abdominal distension ceased, and excessive sweating became of much rarer occurrence. Various attempts were made to get rid of the catheter, but the sphincter was liable to fall back into permanent tonic contracture. Finally, 207 days after the injury (April 10, 1917), we were able to remove the catheter altogether, and from this time he passed his urine automatically; that is to say, the sphincter now participated in the complete act of involuntary micturition.

But throughout this long period of retention, before the establishment of automatic micturition, we were able to show, by repeated observations, that the bladder-wall was capable of expelling its contents actively when they reached a certain volume. Thus, as early as forty-three days after the injury, we found that contraction occurred at about 300 c.c., and half this amount was returned through the catheter in a stream of considerable strength.

On December 23, 1916 (100 days after the injury), we were able to make a more extended series of observations. On passing the catheter 190 c.c. of urine were drawn off, acid in reaction and containing mucus and a small quantity of pus, but no blood. The warm fluid used for washing out the bladder was then allowed to run in through the catheter. At 150 c.c. the column began to oscillate, and at 200 c.c. he evacuated 120 c.c.; a further 80 c.c. were regained by pressure on the abdomen. After 50 c.c. had passed into the bladder sweating began, and became excessive when the abdomen was pressed to evacuate the remains of the fluid. He was then dried and allowed to remain quiet until there was little or no excessive moisture of the head and neck. Fluid was again passed into the bladder, and he began to return it at 120 c.c., passing 70 c.c. The next observation gave 150 c.c. as the adequate volume, and he evacuated 100 c.c.; on another occasion he responded to 125 c.c., passing 65 c.c.

Throughout this series of observations we noticed that, at some definite volume between 50 c.c. and 100 c.c., the fluid began to oscillate in the tube,

showing that it was no longer running into the bladder freely; these oscillations were not respiratory and evidently corresponded to abortive waves of contraction. Their occurrence was the signal for the sweating to begin.

During the time the catheter was tied into the bladder, we were able to make almost daily measurements, and the power of the muscular wall to expel the whole of that volume, to which it reacted, steadily increased. Thus 170 days after the injury (March 3, 1917) the following observations were made: He reacted to 150 c.c., expelling 155 c.c., to 130 c.c. and to 100 c.c., in each case emptying the bladder completely. We then ran in 50 c.c., and, on stimulating the glans penis, the whole amount was evacuated. Again 50 c.c. were passed into the bladder and the sole of the right foot was scratched; a flexor jerk was evoked and he at once evacuated 38 c.c. Finally, as a control, fluid was allowed to run in and care was taken to cause no reflex of any kind; he then evacuated at 100 c.c.

Thus an automatic bladder, which responded to about 100 c.c., could be excited to contraction by half this volume if, at the same time, afferent impulses were thrown into the lower end of the spinal cord from either the sole of the foot or the penis.

Sweating.—In this case the sweating was incredibly profuse; a sponge used to wipe the face and neck could be wrung out as if it had been dipped into water, and blankets and pillows were soaked through in a few minutes. At times, so much fluid was lost that the patient suffered from thirst and the urine was diminished in amount.

The area occupied by the excessive sweating comprised the whole head and neck, both upper extremities and the trunk to the level of the umbilicus; when the outburst was extremely severe or prolonged the sweating might extend to the knees, but was steadily less profuse from the ensiform level downwards. Legs and feet always remained absolutely dry.

In the earlier days, before we were able to relieve the tension in his bladder and before the advent of automatic micturition, he was scarcely ever dry, and was subject to recurrent waves of sweating. They were accompanied by much mental distress and by dilatation of the pupils; at the same time he complained of a painful fulness in the head, occupying the whole occipital region and vertex. As soon as the bladder was relieved, or the bowels were emptied by the passage of fæces or flatus, this headache disappeared.

Later in the course of the case, when paroxysms of sweating did not occur unless induced by some peripheral stimulation, we could study these phenomena more accurately. This sensation of painful distension in the head was then found to be strictly related to the onset of sweating; it appeared with the hyperidrosis and disappeared shortly after reflex stimulation was removed, as, for instance, when the bladder ejected its contents or flexor spasms subsided.

We have already described how closely the onset of sweating was associated with bladder tension. Any stimulus which evoked flexor spasms was also a potent cause of hyperidrosis. If a suitable opportunity was chosen when the skin was in a normal condition, it was only necessary to scratch the sole

of the foot under the bed-clothes for the most profuse sweating to break out over the whole head and neck in association with the flexor spasms. The reflex movements could be evoked by stimulating almost any part of the skin of the lower extremity, by pressure as in grasping the foot or placing the hand firmly on the abdomen, and even by lifting the bed-clothes. No matter how the spasms were produced, they were associated with an outburst of sweating.

Another potent cause for hyperidrosis was abnormal intestinal tension; for not only was the sweating infallibly evoked by an enema, but any collection of flatus also tended to produce an outburst. In the earlier days, before the catheter was tied into his bladder, he was peculiarly liable to periodic gastro-intestinal attacks associated with nausea and the collection of flatus; the abdominal muscles became rigid, flexor spasms increased in the legs, and sweating became very severe. Anything that eased this flatulence, or the passage of the enema with its accompanying relief of tension, was associated with a diminution of the sweating.

Some ten months after the accident, he had reached a condition in which sweating no longer troubled him, because involuntary micturition occurred without effort, enemata were rarely necessary and flexor spasms were seldom excited. But an attack of hyperidrosis could still be evoked experimentally by injecting fluid into the bladder or rectum, or by repeated excitation of a series of flexor spasms.

Case 6.—Gross injury to the lower end of the spinal cord from the lower lumbar segments downwards (right fourth lumbar). All voluntary movement lost below the knees. Ankle-jerks obtained but plantar reflexes absent. Automatic micturition accompanied by consciousness of a full bladder, desire to make water and recognition that the bladder was contracting, but no appreciation of the passage of urine or power to influence the flow. Automatic contraction of the bladder-wall could be facilitated by inducing the cutaneous anal reflex, but not by reflexes evoked from the thighs and abdomen.

Pte. M., aged 38, fell and gravely injured his spine on March 29, 1915. He was a marine, and whilst passing between decks in the dark fell into the open hold of the ship in consequence of the removal of some of the planks which covered the opening. At first he was completely paralysed in both lower extremities, with profound loss of sensation. In this condition he arrived at Netley in October, 1915, and was sent on to the London Hospital on March 6, 1917, for investigation and treatment. His condition was as follows:—

Motion.—All movements were perfect down to the level of the groins, and there was complete paralysis in both legs below the knee. He could extend but could not flex the left knee, and abduction of the thigh and flexion and extension of the left hip were possible. He could not, however, flex or extend the right knee or hip; slight adduction was possible but not abduction. The abdominal muscles acted well, but there is no doubt that the lower

muscles of the back were weak, especially on the right side, and he could not raise himself from his bed without the use of his hands.

The muscles were much wasted below both knees and over both thighs, especially in the lower half, particularly in the right thigh. There was no spasticity or increase of tone in any group of muscles; involuntary movements were absent.

Reflexes.—The knee-jerks could not be obtained, but an ankle-jerk was elicited on both sides: that from the right was stronger than that from the left leg. There was no ankle clonus. The abdominal reflexes were brisk and normal. No plantar reflex of any kind could be obtained.

Sensation.—All sensibility to light touch, prick, heat and cold was lost over the area shown in fig. 1. The borders of the area insensitive to cotton

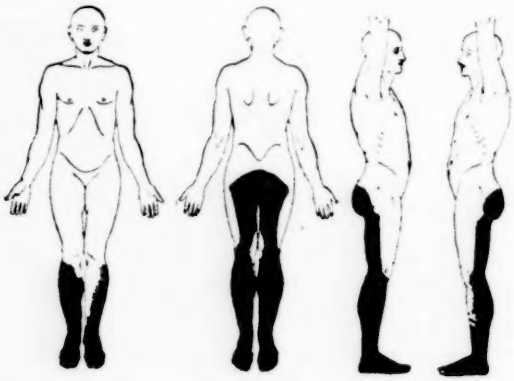

FIG. 1.—To show the extent of the loss of sensation in Case 6.

wool did not differ materially from those of the loss of sensation to prick, heat and cold.

He could not appreciate the pain of pressure with the algometer (base 0·75 cm. in diameter) over either foot or over the anterior aspect of the right shin. Over the left shin 6 kg. was painful. Pressure was recognized as contact over the right foot at 15 kg., over the right shin at 10 kg.; whilst over the left foot he was sensitive to 8 kg. and over the left shin to 2 kg.

He was insensitive to the vibration of a tuning-fork ($C^{0} = 128$) over both feet, and on the right leg this insensibility extended to the knee. On the left side, though profoundly affected, he could just appreciate the vibration for a short distance below the knee.

The bladder.—When first injured he had complete retention of urine, but about four months later he began to micturate automatically. Whilst in the London Hospital he passed urine unconsciously at somewhat frequent intervals; sometimes he had a feeling that he wanted to make water and he

then pressed with his abdominal muscles. Urine was voided in a definite stream but he was unconscious of its passage.

On May 11, 1917 (two years and forty-three days after the injury), the following series of experiments were carried out by us.

A catheter was passed and he had no sensation until it was pushed home into the bladder, when he said "I feel something"; 105 c.c. of clear acid urine, free from pus, were drawn off. Warm sterile water was allowed to run into the bladder, and at 105 c.c. he called out "Now it is coming"; at 107 c.c. he evacuated the total quantity and nothing could be expelled by pressure. At the next observation he expelled the fluid at 98 c.c., and it returned in a vigorous stream; he passed 96 c.c. in the first effort followed by the remainder in a final spurt. At a third observation the bladder voided its contents at 75 c.c., and again at 85 c.c.

He was astonishingly accurate in recognizing when the return of fluid was about to take place. He said: "I suddenly feel the pleasant desire to make water, just as you feel when the bladder is full." Some sensation was produced by the point of a catheter when it reached the bladder and he was conscious of vesical contraction. But he was insensitive to the actual passage of the urine down the urethra and was entirely unable to control it in any way.

No plantar reflex could be obtained in this case, and the superficial reflexes obtainable from above the level of the lesion had no effect on the volume of fluid which found an adequate vesical stimulus. Thus when the left thigh was repeatedly scratched he evacuated through the catheter at 98 c.c., passing 95 c.c., and when the abdominal reflex was evoked rhythmically, first from one half and then from the other half of the abdomen, he evacuated at 70 c.c., passing the whole amount.

At this stage we did not recognize the physiological significance of the anal reflex, evoked from the skin over the gluteal area. Some months later we repeated these observations on the bladder and found that this reflex had a profound effect upon the activity of the bladder. At that time he evacuated his bladder completely when 120 c.c. of fluid had run in through the catheter But if the anal reflex was evoked by scratching the analgesic skin of one or other buttock, the bladder was emptied as soon as 10 c.c. only had entered. When the foreskin of the penis was pricked evacuation occurred at 10 c.c., 15 c.c. and 25 c.c.

Sphincter ani.—When the point of the finger touched the anus the skin was felt to wrinkle up and the resistance in front of the finger increased. This steady resistance was felt as long as the finger was being pushed onwards; but when the finger was allowed to rest quietly in the canal, the sphincter relaxed and held it with a light steady contraction. As the finger was withdrawn the sphincter closed down tightly upon it.

Over an area round the anus extending for 6 cm. in either direction the prick of a pin produced a contraction of the sphincter although the skin was entirely insensitive to touch, pain and thermal stimulation.

Spine.—A radiograph showed that there had been some injury to the body of the fifth lumbar vertebra.

Case 7.—*Destruction of the nerve-roots and conus medullaris from the first lumbar downwards on the left and the second lumbar on the right side. Total flaccid paralysis and loss of sensation below these levels. Complete abolition of reflexes. Automatic micturition; vesical contraction excited at from* 220 *to* 230 *c.c. No facilitation by outside stimuli. Anal sphincter tonic. No cutaneous peri-anal reflex.*

Gunner P., aged 21, was wounded on August 14, 1917, by the fragment of a large shell which burst behind him. He felt as if both legs had been suddenly lopped off. He spent that night in a field ambulance, and was removed next day to No. 24 Casualty Clearing Station. A fragment of metal had entered in the left lumbar region and was found adhering to the pedicle of the twelfth dorsal vertebra. This in turn had been driven across the theca. On August 17 the lamina of the left half of the twelfth dorsal vertebra was removed. The dura was torn at this level and that portion of the pedicle which had been driven across the theca could be removed in part only. (Captain Chisholm, R.A.M.C.)

He was admitted to the London Hospital, under the care of Dr. Head, on August 21, 1917. He then showed a gaping granulating wound extending from the middle line at the level of the twelfth dorsal spine outwards to the left loin. From this wound two sinuses ran downwards and inwards for a considerable distance impinging on bone; one of them seemed to be in connection with the spinal canal, and exuded thin pus in considerable quantities.

Both lower extremities were in a condition of complete flaccid paralysis from the hips downwards, with total loss of sensation below the level of the first lumbar segment, and abolition of all reflexes, superficial and deep.

It was not, however, until the middle of September, 1917, that he was in a suitable general condition for complete examination, and the following observations were made between September 17 and October 6.

Motion.—Both lower extremities below the hips were in a condition of complete flaccid paralysis. He could make no movement at the left hip-joint, but could flex the right feebly. All the muscles of both legs, including the glutei and the right iliac muscles, were wasted; they showed a tendency to fall into fibrillary contraction when stimulated in any way. There were no involuntary movements.

Reflexes.—All reflexes were normal above the level of the umbilicus. Below this level the abdominal reflexes could be obtained, but were feeble compared with those from the supra-umbilical level.

Knee- and ankle-jerks and ankle clonus were absent. No plantar reflexes could be obtained.

Sensation.—Sensibility to prick, heat and cold was lost up to the lower border of the twelfth thoracic segment on the left side and of the first lumbar on the right. The loss to cotton wool corresponded almost exactly to these limits. Pressure was not appreciated almost up to the groin on the left side and as high as the lower third of the right thigh. All recognition of vibration was lost below the great trochanter in both lower extremities, and passive movement was not appreciated up to and including both knee-joints. He was, however,

sensible of movement in the right hip-joint and to a much less extent in the left; here, however, the movement had to be of considerable range to be appreciated.

The bladder mechanism.—A catheter was first passed ten hours after he was wounded, and from that time at varying intervals, about twice daily. On admission to the London Hospital he was passing urine involuntarily, but catheterization was carried out three times a day. The urine was acid and contained no albumin or pus.

On September 17 (thirty-four days after the injury) the following observations were made: The bladder was emptied and 190 c.c. of urine withdrawn. When the warm washing fluid was allowed to run in he evacuated at 225 c.c., passing 230 c.c.; nothing could be recovered by pressure. The second time the bladder contracted at 220 c.c. and the whole was ejected. On repeated deep breathing he evacuated at 230 c.c., and when the abdominal reflexes were evoked ejection took place at 220 c.c.: in both cases he passed the exact amount run in from the burette. No reflexes could be evoked by scratching the soles, and this stimulus had no effect on the activity of the bladder. No peri-anal reflex could be obtained.

Thus at the end of a month at any rate automatic micturition had been established and contraction of the bladder-wall could not be influenced by stimuli from without.

Sphincter ani.—An enema was administered every night and he felt nothing until his abdomen became uncomfortable. He was not conscious of the return of fluid and fæces, except by the feeling of relief from discomfort.

The anal sphincter was tight, but yielded to continuous pressure applied slowly, even without the exercise of much force. On withdrawing the finger a firm vigorous contraction occurred as the volume in the rectum decreased; this ended on complete removal of the finger in a permanent normal tonic contraction.

No anal reflex could be excited by stimulating the skin.

Case 8.—*An instance of modified Brown-Séquard paralysis due to a wound of the left side of the neck injuring the spinal cord in the lower cervical region. Weakness and some loss of sensation in the left arm and hand. Total loss of sensation to pain, heat, and cold, over the right half of the body from the nipple level downwards. Much over-reaction to uncomfortable stimuli over the left half of the body during the first few months after the injury. Profound want of appreciation of the vibrating tuning-fork over the left half of the body from the level of the fifth rib downwards; on the right half this loss extended to just above the hip-joint. No affection of light touch or pressure over the trunk or lower extremities. Voluntary movement rapidly returned in both lower extremities, but was always better in the right than in the left. Flexion reflexes evoked from both lower limbs. But from the right leg a flexor spasm of the massive type was evoked which facilitated the evacuation of the bladder, whilst from the left the characteristic flexion reflex had no effect on vesical activity. Primary extension*

could be produced reflexly in the left leg but not in the right. The bladder acted involuntarily and automatically, but the patient knew when fluid was about to pass. Excessive sweating, mainly over the head and neck, which could be evoked by visceral afferent impulses affecting the spinal cord below the lesion.

Lieutenant G., aged 24, was wounded in the neck by a fragment of a high explosive shell on August 24, 1916. He lost power immediately in the left arm, and was paralysed from the level of the nipples downwards.

He was hit at 4.30 p.m., as he was moving along the trench to empty his bladder. No catheter was passed until midday on August 25, nineteen and a half hours after the injury, but he felt no distension. Retention of urine was complete, and a catheter was passed every twelve hours until about a week after he was wounded, when the intervals were reduced to every six hours, in consequence of the discomfort associated with distension of the bladder. Urine began to pass in small quantities automatically about fifteen days after he was wounded, and within the next two days catheterization was stopped altogether.

The condition of this patient during the fortnight following his admission to the Empire Hospital, under the care of Dr. Head, on September 24, 1916 (thirty-one days after the injury) was as follows:—

The wound consisted of a minute horizontal slit, 1 cm. in length, situated on the left side of the neck, 11 cm. below the tip of the left mastoid process. It had closed, but was surrounded by some staining from extravasated blood, which subsequently developed into a huge yellow bruise, occupying the whole of the left supra-clavicular fossa.

A radiograph showed no foreign body, and as there was no exit wound it is suggested that the injury may have been due to a piece of aluminium.

Motion.—The right arm was in every way normal, but there was considerable loss of power and want of co-ordination in the movements of the left upper extremity; this was particularly evident in the small muscles of the hand.

He was completely paralysed from the level of the fourth rib downwards on both sides. There was, however, a tendency to involuntary flexor movements in the left leg, and a tremor of the left leg, which did not either flex or extend the limb.

Reflexes.—At this stage there was no great difference between the jerks obtained from the two upper extremities. The knee-jerks and ankle-jerks were absent, and ankle clonus could not be obtained. No response was evoked when the right sole was scratched; but stimulation of the left sole produced a distinct flexion and adduction of the left thigh, with no movement of the great toe.

Sensation.—Over the whole left half of the body and pre-axial half of the left arm he reacted excessively, and complained bitterly when he was pricked. This made it extremely difficult to discover to what extent sensation was lost over these parts; but it was certainly greatly diminished over the left leg below the knee and over all the sacral areas on the buttock and back of the thigh.

On the right half of the body sensation to prick, heat and cold was abolished up to the nipple level.

Cotton wool and deep pressure were universally appreciated and well localized. The vibration of a tuning-fork was not recognized over the whole of both lower extremities, and as high as the iliac crests; at this stage we could not determine with certainty the loss on the thorax, but this form of sensibility was not normal until the nipple level was passed on either side. Passive movement could not be recognized in the lower extremities, except, perhaps, at the hip when it was very extensive.

Pupils, &c.—The left pupil was smaller than the right and dilated less to shade. Moreover, the left palpebral fissure was perhaps a little smaller than the right.

Urinary System—He had no voluntary control over micturition, but passed about 150 c.c. at varying intervals, amounting in all to between 1,700 and 2,200 c.c. in twenty-four hours.

He could recognize the passage of urine, and knew when fluid was being injected into his bladder. When about 280 c.c. had entered he experienced "a nervous wave" which seemed to start in the abdomen, pass up the body, down the arms and into his head. This "sort of shiver" preceded evacuation, whether he passed urine automatically or whether he was ejecting fluid from his bladder through a catheter in the course of vesical lavage. He knew when he was about to evacuate fluid and experienced that pleasure which normally accompanies the passage of urine; but he had no desire to micturate.

The urine was alkaline and contained a good deal of pus; the amount of albumin corresponded roughly to the quantity of pus.

Sweating.—There was a good deal of sweating over the right half of the head and neck; the left half was almost dry.

The subsequent observations we made on this patient up to the end of July, 1917, will be summarized under the following headings of *Motion, Reflexes, Sensation, Urinary System, Sweating, &c.* On February 15, 1917, his bladder was opened suprapubically and the condition of the urine greatly improved; but the kidneys were infected and he died somewhat suddenly, after a short period of pyrexia, on August 21, 1917. The suprapubic wound was allowed to close on April 15, and from that date the bladder was washed out through a a catheter only.

Motion.—Voluntary power slowly returned, appearing first in the right leg. By the eighty-seventh day after the injury (November 19, 1916) he could flex and extend the right knee; the left knee could be extended, but not flexed voluntarily. He could plantar-extend the right foot, but was unable to dorsiflex at either ankle. All involuntary movements consisted of flexor spasms, which adducted the thighs; these were evoked by removing the bedclothes or by any manipulation of the lower extremities. Both limbs were somewhat wasted and flabby unless they had been thrown into spasmodic flexion.

By the one hundred and seventy-fourth day the condition had somewhat changed. The left upper extremity had wasted considerably, especially the

interossei and thenar muscles. All movements could be performed, but abduction of the fingers was weak and tremulous. The left arm was inco-ordinate and he used it little in his daily life.

He could voluntarily flex and extend the right hip and knee and strongly plantar-extend the right foot. But he could not dorsiflex it or make any movement of the toes. All the movements of the left lower extremity were feeble. Dorsiflexion of the foot and movements of the toe were impossible, but he could plantar-extend, though less strongly than on the right side. At the knee and at the hip flexion was feeble, but extension relatively strong. Involuntary flexor movements occurred in both limbs, but were more frequent and more pronounced in the right than in the left. If he straightened the left leg it fell into rigid extension; this did not occur in the right leg.

Two hundred and eighty-six days after the injury (June 6, 1917) the condition was as follows: The left arm was still wasted and inco-ordinate but was much more useful in daily life; he could not use it to change his position in bed and to move objects on the bed-tray.

Voluntary power had greatly improved in the right leg. He could flex, extend, adduct and abduct it at the hip; flexion and extension at the knee and plantar extension at the ankle, together with downward movements of the toes, were strongly performed. We were doubtful if there was any true voluntary dorsiflexion or upward movement of the toes.

In the left lower extremity, extension, abduction and adduction of the hip were well performed but flexion was weak. He could flex and extend the knee, but, whilst flexion was weaker than in the right leg, extension was quite as strong. He could plantar-extend but could not dorsiflex the foot; both upward and downward movements of the toes were possible, but the latter were the stronger. Apart from extension, voluntary movement was throughout weaker in the left lower extremity than in the right.

All involuntary movements in the right leg were of the flexor type, with active extension as a secondary phase. In the left leg a flexor spasm was the most common, but extension could occur as a primary motor reaction.

Reflexes.—Within fifty-two days after the injury, the left knee-jerk had appeared, though the right was still absent. The ankle-jerks were not obtained and there was no ankle clonus. The plantar reflex from the right foot was a slight downward movement of the toes with no hamstring contraction, whilst that from the left sole caused distinct flexor contraction at the knee but no movement of the foot or toes. Seven days later both knee-jerks were present, but the other reflexes were exactly as described above.

Within eighty-seven days from the injury a great change had occurred. Both knee-jerks were greatly exaggerated, the ankle-jerks were brisk, and ankle clonus was present on the right side, but absent on the left. When the right sole was scratched the great toe moved upwards, the other toes became separated and a true flexor spasm was evoked, which affected the abdominal muscles. Scratching the left sole caused contraction of the inner hamstrings, but the great toe remained stationary; the abdominal muscles did not contract with the produc-

tion of this reflex. No reflexes could be obtained by direct stimulation of the abdomen, except on the right side above the umbilicus

By the two hundred and forty-first day after the injury the difference between the reflexes from the two lower extremities had become accentuated; this period is important, because it was on this day that the striking series of measurements were carried out on bladder capacity which are detailed on p. 262. Scratching the sole of the right or insensitive foot evoked a full flexor spasm with upward movement of the toe and contraction of the right half of the abdomen. This was accompanied by crossed extension in the left leg; the toe moved downwards, the foot was plantar extended and the quadriceps contracted sufficiently to pull up the patella.

On the other hand, scratching the left sole led to a flexion reflex of the left leg unaccompanied in most cases by any definite abdominal contraction; any movement of the rectus abdominis which occurred was feeble compared with that evoked by stimulating the right sole. The flexion in the left lower extremity, produced by scratching the left foot, was associated with slight but definite contraction of hamstrings in the opposite (right) limb.

Thus stimulation of the analgesic foot (right) produced a full flexor spasm accompanied by strong contraction of the abdominal muscles and associated with a crossed extensor reflex; stimulation of the left foot, evoking painful sensations, produced flexion accompanied by little or no abdominal contraction and associated with crossed flexion at the right knee. The first of these reflex responses (from the right foot) was associated with facilitation of detrusor activity, whilst the second (from the left foot) had no effect on the bladder.

Sensation.—The over-reaction to painful stimuli on the left half of the body gradually passed away, and it became possible to determine more accurately the condition of sensibility.

Over the inner border of the left forearm sensation was definitely duller than elsewhere, both to pricking and light touch, but was nowhere lost completely.

The whole of the right half of the body and the right lower extremity below the level of the nipple was insensitive to painful and thermal stimuli. Touches with cotton wool were everywhere appreciated and correctly localized. Vibration was not recognized, apart from the contact of the tuning-fork, over any part of the right lower extremity; it was, however, appreciated over the anterior superior spine and crest of the ilium. He also failed to recognize passive movements in the right lower extremity below the hip-joint.

The left half of the body and left lower extremity were sensitive to light touch, pricking, heat and cold, except that sensibility to prick was a little dulled on the outer aspect of the left leg and dorsum of the foot. On the other hand, vibration was not appreciated from the level of the fifth rib downwards, and recognition of passive movement was lost in the left lower extremity.

Pupils, &c.—Within eighty days of the injury the pupils became equal and dilated well to shade; the palpebral fissures were about equal in size.

Urinary System.—He never regained voluntary control over micturition,

although he was conscious of distension of his bladder, knew when it was about to evacuate its contents, and recognized that urine was passing.

On April 22, 1917 (two hundred and forty-one days after the injury) the following measurements were made. He felt the passage of the catheter, which withdrew 150 c.c. of urine. On allowing sterile warm water to enter the bladder it contracted at the following volumes: (1) At 115 c.c., and he passed 120 c.c.; (2) at 70 c.c., passing the same amount; (3) at 90 c.c., passing 105 c.c.; (4) at 100 c.c., passing the full quantity. Then, after 30 c.c. had been permitted to run into the bladder, the right (insensitive) sole was stimulated, and he immediately evacuated the whole amount: 30 c.c. was again allowed to run in, and the left (sensitive) sole was stimulated, but no evacuation occurred, in spite of the appearance of a powerful flexion reflex. More fluid was allowed to enter, and at 40 c.c., 50 cc., and 60 c.c., the left sole was repeatedly scratched. No effect whatever was produced on the activity of the bladder-wall, and at 70 c.c. he called out: "It will fire off by itself now!" At that moment the fluid began to return, and he passed 70 c.c. in all. Thus, scratching the sensitive foot had no effect on the contraction of the automatic bladder, whilst stimulation of the insensitive (right) foot greatly facilitated the return of fluid before it reached one-half the volume that usually formed an adequate stimulus.

These observations were repeated on July 26, 1917 (three-hundred and thirty-six days after the injury), with the following results: (1) When 135 c.c. of sterile water had run in, he passed 135 c.c.; (2) at 160 c.c. he passed the full amount; (3) at 150 c.c. he passed 145 c.c. When the right sole was stimulated during the inflowing of the fluid, he evacuated at 70 c.c., passing the full amount; but, on stimulating the left foot in the same way, he did not evacuate until 160 c.c. had run in, an amount to which he would have reacted without evoking any somatic reflex. Deep breathing caused evacuation at from 30 to 80 c.c.

Sweating.—During the first three weeks excessive sweating occurred on the right half of the head and neck, but not on the left; gradually a similar hyperidrosis appeared to the left of the middle line, and, finally, no definite difference could be noticed between the two sides.

Usually the sweating was profuse over the head and neck, and died away rapidly towards the ensiform level on the trunk; but when the manipulations which evoked it were long continued it extended to the feet. The lower extremities and lower half of the trunk, however, always sweated less profusely than the head and neck.

An outburst of sweating could be evoked most rapidly and most certainly from the bladder. If the catheter was inserted properly, and the bladder-wash could flow back freely at the moment of contracting, he did not sweat; but if for some reason, such as blocking of the catheter by a plug of mucus, free return was hindered, he burst into intense sweating over the face and neck. After the bladder had been opened suprapubically on February 15, 1917 (one hundred and seventy-five days after the injury), all excessive sweating ceased, except when the box ("tortoise") shifted on the abdomen, or the free

flow of urine was checked by some mechanical defect. On one occasion the drainage tube from the bladder, passing through the suprapubic wound, became blocked by a small calculus, and hyperidrosis came on again in a violent form to our profound bewilderment.

Excessive sweating was not correlated with that "thrill" or "shiver" which normally accompanies evacuation of a full bladder. In fact, this sensation seemed to be evoked by the opposite condition to that which caused sweating. Before the operation he could tell with remarkable accuracy when his bladder was about to empty itself, during our experimental observations, and contended that he "always knew by a nervous wave, which seemed to start in his abdomen, and passed up to the head and down his arms"; it was "a sort of shiver," and it immediately preceded passage of urine automatically or evacuation of the fluid inserted through the catheter. With this sensation he never sweated; it was always associated with an easy passage and free outflow. Any obstruction destroyed this sensation, and replaced it by sweating, which was accompanied by a definite feeling of discomfort.

Sweating could also be evoked by the manipulations necessary to administer an enema. When an enema was given in our presence, he could feel the insertion of the nozzle of the syringe. Then after the first few ounces of fluid were pumped in, he said: "I have a feeling as if the passage were being forced open." After receiving about 300 c.c. he said: "I've got a nervous feeling which runs up the body down my arms into the back of my head and over the front of the scalp; it also runs down the front and inner aspect of both thighs, more on the left (sensitive) side than on the right. This thrill is not unpleasant, but as the injection goes on it becomes unpleasant, just as it is unpleasant when you have to strain on stool." No sweating occurred until this thrill became converted from a pleasant to an unpleasant sensation. The pleasant visceral "thrill" was not associated with a stimulus to sweating; but obstruction, with its necessary discomfort, evoked hyperidrosis.

Whenever an outburst of sweating was produced, from whatever cause, the pulse tended to become slower, more forcible, and somewhat irregular. We could not satisfy ourselves, however, that there was any certain coincident change in the pupils.

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THE REFLEX FUNCTIONS OF THE COMPLETELY DIVIDED SPINAL CORD IN MAN, COMPARED WITH THOSE ASSOCIATED WITH LESS SEVERE LESIONS.

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CHAPTER I.—INTRODUCTORY AND HISTORICAL.

THE numerous cases of spinal injury which have appeared during the War have given us an unprecedented opportunity for investigating the functions of the cord; and especially of settling more definitely than has hitherto been possible the vexed question of whether or no the spinal cord in man, when completely disconnected from brain control, can

function by itself; and if the reflex activities are preserved, whether these compare at all with those known in the spinal animal.

This paper is based on observations made during the last two years on many cases of spinal injury, in eight of which, as proved at operation, the cord had been totally transected. I shall bring forward evidence to show that not only can complicated adapted acts be performed by the parts controlled by the isolated cord segments, but also that they follow the same principles which, according to Sherrington and others, seem to guide the reflex activities of spinal animals.

The cases here recorded differ from the majority of those hitherto used in argument for or against the autonomy of the human isolated spinal cord for the following reasons :—

(1) The patients were all healthy young adults.

(2) The transection of the cord was in each case sudden, in that the lesion was produced by rifle or shrapnel bullets, or by pieces of shell-casing travelling at high velocity.

(3) In each case complete *anatomical* division of the cord was demonstrated either at operation or at autopsy.

(4) The effect of toxic febrile complications from urinary infection, wounds, bed-sores, &c., has been taken into account.

More suitable cases in which to study the symptomatology of total division of the spinal cord could not have been hoped for, and here I wish to lay stress on the great advantages we possess over previous observers for the study of these neurological problems. Any light that has been thrown on the innate functions of the cord is due not only to the unique cases at our disposal, but principally to the attitude of mind induced by the monumental work of Sherrington.

It may be well here to review briefly some of the opinions that have been held on the effects of spinal cord transection. For a fuller account reference should be made to the papers of Reynolds [31], Bruns [10] and Warrington [43].

Since the middle of the last century, when clinicians began to be interested in the results of physiological experiments in animals, a battle has been raging, sometimes fierce, sometimes lulled, on the question of the functional activity of the isolated segments when the spinal cord is completely divided in man. The complicated reflex actions exhibited by the spinal frog, dog, cat and monkey, fascinated clinicians; and many of the ablest believed and taught that similar though less complicated activities could be evoked in man. They maintained that when completely cut off from the influence of higher

centres situated in the brain which exert an inhibitory control over spinal reflex action, the reflex arcs in the caudal segments not only retain their functional integrity but that heightened reflex activities are displayed.

Thus, in 1884, Bryom Bramwell [7] wrote: "The reflexes passing through the inferior segments are exaggerated. With the occurrence of secondary degeneration the paralysed muscles supplied by the inferior segments become tense and rigid." The muscular hypertonia was to his mind due to "irritation" caused by degeneration of the pyramidal tracts.

Gowers in 1886, writing on "Acute Transverse Myelitis" [19], said: "An acute lesion in any part of the cord may cause an initial loss of reflex action in the part below, but if the lesion is above the lumbar enlargement reflex action returns in the course of a few hours. Frequently there is no initial depression. Subsequently the reflex action becomes excessive, that from the skin rapidly, that from the muscles more slowly. Ultimately each attains a high degree of exaltation. . . . The muscles are at first flabby and toneless during the stage of initial depression of reflex action, doubtless from the same influence. This condition soon passes off if the lesion is above the lumbar enlargement and as reflex action becomes more active the muscles regain their tone." How true and accurate this description is will be seen from the cases to be recorded in this paper.

Again he writes: "Excess of superficial reflex action indicates withdrawal of the cerebral controlling influence of the reflex centres and marked excess of the muscle reflexes suggests the existence of a descending degeneration in the lateral columns, since it implies impaired function of the lowest part of the pyramidal tracts."

Thus exaggerated reflex activity in the spinal segments cut off from the brain was at that time the generally accepted doctrine, and so it continued to be till, in 1890, Bastian published his paper [5] "On the Symptomatology of Total Transverse Lesions of the Spinal Cord." In it he expressed the view that a complete lesion of the cord is accompanied by flaccidity of the limbs and absence of tendon reflexes. From clinical and pathological evidence he deduced that the following symptoms occurred when the spinal cord had been totally divided at the lower cervical and upper dorsal levels.

(1) Complete paralysis of the legs and abdominal muscles.

(2) Loss of sensibility below the level of the lesion.

(3) Muscles flabby and toneless.

(4) For a long period only slight wasting of the paralysed muscles.

(5) Loss of abdominal and cremasteric reflexes and of the tendon jerks in the legs, the only reflex response obtained being an occasional slight movement of the toes when the soles of the feet are strongly tickled.

(6) The skin is dry and scurfy.

(7) For the first ten to fourteen days there is complete retention of urine. This is followed by periodic reflex evacuation of the bladder which is never complete, two to four ounces [about 50 to 100 c.c.] remaining as residual after each act.

The bowels are confined and are relieved only by aperients and enemata. At these times there is incontinence of fæces (reflex evacuation).

Accepting Hughlings Jackson's view that tonus in skeletal muscles is maintained by cerebellar influence on the spinal centres and that the knee- and ankle-jerks depended on the presence of tone in the quadriceps and calf muscles, he was of opinion that the absence of tendon reflexes in the legs was due to interruption of the efferent cerebellar tracts.

Bastian's paper was followed by several other communications in which his views were on the whole upheld. Notable among his supporters were Bowlby [6] and Thorburn [41] in this country and Bruns in Germany. Reynolds [31] in 1895, reviewing the literature, came to the conclusion "that Bastian's description of the symptomatology of total transverse division of the cervical or upper dorsal region of the cord was correct and that his cerebellar theory was the most feasible explanation of the abolition of tonus and deep reflexes."

This doctrine though generally accepted did not gain universal credence. Several important contributions were made to the foreign literature during the last decade of the century in which proof was brought forward to show that Bastian's law was at all events not absolute. Yet the belief in the syndrome was not seriously shaken in this country. In 1902, Warrington [43], in a critical review, after analysing several of the cases recorded by Gerhardt [16], Senator [32], Brissaud [9], Raymond and Cestan [30], Nonne [29] and Brauer [8], summed up as follows: "A consideration of the above recorded cases affords strong evidence for the belief, that whilst in general the symptom-group described by Bastian follows complete transverse lesions of the cord, yet when the disease is of a slowly progressive nature the reflex functions of the cord may be retained and the muscular tone be unimpaired, and also that in some cases very severe symptoms

approximating to those generally found after complete transverse lesions may be present and yet the anatomical lesion be slight or incomplete."

He briefly outlined some of the theories that had been put forward to explain the loss of the tendon reflexes in these cases. Egger [15], Erb and Hitzig (as quoted by Egger) and Strümpell [40] considered that it was due to functional and nutritional deterioration of the grey matter of the lumbar centres brought on in consequence of the severity of the lesion. He gives in more detail the conclusions arrived at by Bischoff after full consideration of the subject: "After a transverse lesion in the cervical and upper dorsal region of sudden nature and complete or almost complete extent, there is besides the motor and sensory paralysis an almost complete paralysis of the vaso-motor nerves for the lower part of the abdomen, and consequently a fall in the blood pressure, filling of the great abdominal veins and hence anæmia in the other body parts and in the grey matter of the spinal cord, whose ganglion cells undergo functional and nutritional changes. He considered that in this way there is an explanation of the cases of return of the knee-jerk where previously there had existed all Bastian's signs of a complete transverse lesion. The reason this return is not oftener observed is because secondary lesions develop, such as decubitus, septic infections, fever, &c."

Gerhardt, he said, believed that the flaccidity and absent reflexes were due to inhibition brought about by irritation of the long tracts at the site of the lesion. Brauer while supporting the inhibition theory suggested that damage to the roots produced by disturbance of the cerebrospinal fluid explained the absence of reflexes in some cases.

Warrington favoured Bastian's view that muscular flaccidity and abrogation of reflex functions in the isolated segments were due to discontinuity of the long efferent pyramidal and non-pyramidal (mesencephalic) tracts, and based his support on the evidence afforded by two classes of disease: (1) Sub-acute combined degeneration of the cord of Batten, Russell and Collier, and (2) disease of the spine in which spasticity gives place to flaccidity and loss of knee-jerks without any indication of involvement of the lumbar enlargement. He quotes such a case and adduces that spasticity resulted from lesion of the pyramidal tracts, whilst the later flaccidity was caused by involvement of the efferent extra-pyramidal paths.

The next important contribution to the subject was made by Collier [13] in 1904. He believed, as the result of examination of many cases in which the lesions were due to wounds of the spinal cord,

fracture-dislocations, compression and acute transverse myelitis, that "not only are the knee-jerks and other deep reflexes permanently abolished in the region supplied by the caudal segment of the divided spinal cord, but in addition the muscles waste and lose their faradic excitability and the sphincters lose their tone, the only sign of self-action remaining in the isolated part of the spinal cord being the occasional presence of certain of the skin reflexes (plantar reflexes) in much reduced degree. These phenomena occur in the absence of any recognizable structural change in the ventral horn cells, ventral roots and peripheral nerves of the paralysed region." He pointed out that long continued faradization of the lower limbs may cause the return of the knee- and ankle-jerks for a certain time after their disappearance by renewing the activity of the lumbo-sacral centres. In his view, the almost complete abrogation of function of the isolated segments in man was a further stage of the much diminished reflex activity of spinal apes and indicated the increasing hierarchy of the brain.

Sherrington's monumental work on the functions of the central nervous system as integrator has forcibly directed bedside workers to new methods of approach in the investigation of disease of the brain and spinal cord. When writing on spinal shock he says ([33] p. 247): "Spinal transection is followed in the monkey by longer lasting shock—included in which I suspect is isolation-dystrophy—than in other animal types observed in the laboratory. My results in monkeys bore out that which Bastian, Bowlby and Bruns, contrary to previous observers, have described as the typical condition in man after spinal injury completely severing the cord. Thus, I found the knee-jerk sometimes inelicitable during a month or so after mid-thoracic transection in the monkey, whereas in the rabbit its abeyance lasts usually but ten minutes or a quarter of an hour." And again, "The deeper depression into which the higher animal as contrasted with the lower sinks when made 'spinal,' appears to me significant of this, that in the higher types, more than in the lower, the great cerebral senses actuate the motor organs and impel the motions of the individual."

Walshe [42], in his paper on "Reflex Phenomena in Spastic Paralysis of the Lower Limbs," agrees with Sherrington and Collier that the great gulf which separates man and the ape from the dog and cat in the functional activity shown by the transected cord is due to the greater intensity of "spinal shock" and to succeeding isolation changes in the nervous elements themselves brought on by withdrawal of influences normally exerted on the isolated segments by centres

farther headward. He maintains that though the paralysed muscles are flaccid and that as a rule all signs of reflex activity in the quadriceps and calf muscles are gone yet the flexion reflex of the hind limb can often be obtained in minimal degree. Thus in three cases of physiologically complete cord lesion, which he observed, on stroking the sole visible contraction of the hamstrings and tensor fasciæ femoris, dorsiflexion of the foot and upgoing fanning toes were obtained while knee- and ankle-jerks could not be elicited. Whilst admitting that the condition of flaccid paralysis with depressed reflex activity in the lower limbs of "spinal" man differed widely from the great functional activity displayed by the isolated cord in lower animals, he maintained that the difference was one of degree.

Two recent communications must also be considered. Gordon Holmes [22], in the Goulstonian Lectures of 1915 on "Spinal Injuries of Warfare," concluded from his observations in the earlier weeks on a large number of cases that, in total transverse lesions of the cord, the knee- and ankle-jerks were probably permanently absent. In one case, however, in which a piece of shell-casing seemed to have destroyed most of the fourth, fifth, sixth, and seventh thoracic segments, though the totality of the lesion had not at the time of writing been corroborated by microscopical examination, he was able to obtain feeble knee-jerks from the fifteenth day onwards. The abdominal and cremasteric reflexes he found to be more easily abolished than the tendon-jerks, and when the lesion lay above the mid-dorsal level, they never recovered so long as there was any obvious motor weakness of the lower limbs. The response to plantar stimulation varied. Sometimes no movements of the toes nor contraction of the hamstrings or of other muscles could be obtained even for several weeks after the infliction of the spinal injury. In some cases, in which he concluded that the severance of the cord was not total, a very interesting movement of the toes was evoked, consisting of a simple flexion of the great toe, often associated with slight flexion and adduction of the smaller toes. I was able to elicit this response in one undoubted case of complete cord transection, and in several others in whom all the symptoms of such a lesion were presented, though since the cord was not explored it could not be verified. I agree with Holmes that the toe movement cannot be attributed to direct mechanical irritation or to stretching of the small muscles of the sole, as it can be evoked by stimulation of the outer border of the planta. He believed it to be a "uni-segmental reflex." Sometimes contraction of the inner hamstrings was the only motor-reply to sole excitation, but as a rule this

was associated with slight flexion of the toes. As will be seen later, these, too, may be obtained in cases of total transverse division of the cord.

In all severe lesions he found the lower limbs to be flaccid as early as one day after the injury, and they became flabby and toneless in three or four days. If the lesion was complete the muscles remained flaccid and wasted gradually, and later underwent fibrous contraction, especially those of the calf and the flexors of the toes.

In four cases where the lesions were severe or total, and involved the lowest dorsal or highest lumbar segments, "automatic" movements of alternate flexion and extension of the lower limbs were observed. They resembled the steppage movements of the spinal dog. Only with lesions at this level did they occur, and they were noticed as early as the second day.

I have only referred to those parts of this paper in which Holmes discusses the reflex symptomatology of severe and complete lesions, and it should be read carefully by all who are interested in spinal injuries. In estimating the value of signs in the early stages as indicating the severity of the injury he is extremely guarded. He says: "The prognosis during the first two weeks in any one case is extremely difficult, and it must be admitted that there is no one sign or symptom from which we can draw reliable conclusions on the severity of the lesion, or from which we can say when there is complete motor and sensory paralysis, as there nearly always is in the earliest stages, whether the cord is completely divided or not. It must be remembered that though neither the cells nor the fibres of the spinal cord do regenerate, very considerable improvement may occur, as at least part of the early symptoms are due to œdema, circulatory disturbances, and to incomplete damage. The structural damage is consequently not always parallel to the functional loss. We have seen that the knee-jerks are absent for a time with lesions of all degrees of severity, and this consequently cannot be a guide in prognosis. The most reliable information is perhaps given by the state of tone in the muscles of the lower limbs; after three or four days the legs are generally very flaccid and their muscles toneless when the lesion is severe and irrecoverable, and gradually become more so and waste. The preservation of tone in the muscle is, on the other hand, an indication that some improvement may be expected. Valuable information can be also obtained by stimulation of the soles, as the amount of reflex movement that results varies more or less inversely with the severity of the injury. When

this is incomplete, no reflex muscle contraction can be, as a rule, elicited, while in all stages of slighter damage a brisk withdrawal reflex can be obtained. Probably no serviceable recovery can be expected if the plantar responses are flexor."

The clinical picture of complete cord transection alters so much at a stage later than that at which Holmes made his observations in hospitals in France that many of his suggestions cannot be accepted. By the time the patients arrive in England the spinal segments caudal to the lesion have begun to recover their functional activity and soon cutaneous and tendon reflexes can be evoked, the muscles regain their tone, vigorous flexor spasms of the lower limbs occur and the bladder and rectum void their contents reflexly.

Collier [14], in an address delivered before the Medical Society of London in March, 1916, agreed on the whole with the conclusions arrived at by Gordon Holmes. He cited a case of destruction of three thoracic segments of the cord in which he had carefully observed the condition of the plantar reflexes within a few hours of the injury and repeatedly until death occurred on the fourth day. The toe movement in response to sole stimulation was "extensor" from the first and went against the view that the early presence of this response or its early return indicates that the lesion is not complete and that the prognosis for recovery is good.

He believes that there are four consecutive stages in the condition of the plantar reflexes following a severe lesion of the cord: (1) An initial extensor response. (2) Either a complete absence of any reflex which may be the result of shock or of isolation alteration, or a reduced flexion reflex which is the result of isolation alteration coming on rapidly. (3) The extensor response which when persistent is indicative of a less severe lesion or alternatively of more recovery than the reduced flexion reflex. (4) The normal flexion reflex which returns when recovery is complete.

In the cases I have observed, some of which are to be described in this paper, the toe phenomenon was either "extensor" from the first or "flexor," becoming gradually "extensor" as time went on. I cannot, however, agree with the opinion put forward by Collier that a persistent "extensor" response means that the lesion is incomplete.

I take the opportunity here of expressing my sincere thanks to Dr. Batten, Dr. Buzzard, Dr. Collier, Dr. Guthrie, Dr. Head and Dr. Wilson for their kind assistance and valuable advice, and for permission to publish my records of patients under their care at the Empire Hospital for Officers.

Chapter II.—A Typical Case of Complete Division of the Spinal Cord.

No. 1.—Total division of the spinal cord at the level of the sixth dorsal segment. Complete loss of voluntary power and sensation below this level. Great reflex excitability of the isolated portion of the cord. Flexor spasms of the central abdominal wall and lower extremities. Knee- and ankle-jerks brisk. Extension reflexes of the lower limbs could not be evoked. Flexion reflex elicited by noxious stimulation of any part of the limb. Localized contraction of the external oblique and general flexor spasm of the abdominal wall were both obtained. Coitus reflex evoked. "Mass-reflex" obtained by noxious stimulation of the abdominal wall and lower extremities. Profuse sweating from the palms of the hands, trunks and legs which could be evoked by injecting the bladder or rectum, or by producing flexor spasms from parts below the lesion. Automatic bladder and rectum. Facilitation of detrusor action of the bladder by any reflex activity below the level of the lesion. Cystitis not prominent. No massage or electrical treatment to paralysed muscles.

Lieutenant M., aged 28, was wounded by a shrapnel bullet in the spine on August 6, 1916.

He was hit in the back of the chest while trying to get through the enemy's barrage on his way to the observation post of the battery. He fell at once. His mind was perfectly clear. The feeling he had was that he was "blown in two," but he experienced no pain. He thought the part of the body below the middle of the chest and the lower limbs were "gone." The arms were not affected and he found no difficulty in breathing. He was not conscious of any abnormal sensations over the heart and did not feel faint. Four orderlies dragged him back to shelter in a dug-out, and thence he was carried on a stretcher to the Forward Dressing Station and later to the Field Ambulance. During the first stage of the journey, he was "half conscious." Later on being transported in a motor ambulance to the Casualty Clearing Station, he suffered a good deal of pain in the wound. He lay on his face on the stretcher. He vomited at the Casualty Clearing Station without warning or nausea; "The stuff simply came up with a rush." No great effort was expended in the act, but following it he had severe "cramps" round the chest above the nipple-line. The wound was said to have bled freely. At this time the lower limbs and abdomen were flaccid and powerless; sensation was lost below the sixth rib and no urine was passed. The bladder was first emptied by catheter six and a half hours after the injury. He did not recollect when last he passed urine voluntarily. He was kept at the Casualty Clearing Station for twenty-four hours and was then transferred to No. 20 General Hospital. On the day following his admission there he had another "bout of cramp" round the upper part of the chest and the wound again bled. The wound was small and little pus exuded from it. His bladder was emptied night and morning by catheter; it was

washed out once only in the ten days prior to his admission to the Empire Hospital on August 16. He was kept at No. 20 eight days, and during that time the condition of the lower extremities and abdomen did not alter. For a week after he was wounded his appetite was poor, and after food he had no abdominal sensations. In an X-ray examination the bullet was seen in the mid-line over the sixth dorsal vertebra and seemed to be lying close against the posterior aspect of the body of the vertebra.

He was admitted to the Empire Hospital for Officers, Vincent Square, on August 16, under the care of Dr. Collier. He had "stood the journey" well. The wound (2 cm. by 1½ cm., and situated 5 cm. to the right of the fifth dorsal spine) was clean and healing and had been dressed with dry gauze.

Condition on August 17, 1916 (*Eleven Days after the Injury*).

Motion—The muscles of the arms, shoulders and upper part of the chest acted well. Total flaccid paralysis of all muscles of the trunk below the sixth rib and of the legs. The diaphragm acted well. No involuntary movements of the legs were seen, nor was there appreciable wasting of the muscles.

Reflexes.—Arm-jerks were brisk and equal. Abdominals, cremasterics, bulbo-cavernosus, knee-jerks, ankle-jerks, ankle clonus and plantars were absent. On scratching the soles movement of the hamstring tendons was not felt on palpation. The penis had been flaccid since he was wounded and erection could not be induced by stimulation of the skin round the genitals. He had had no seminal emissions.

Sensation.—A narrow irregular hyperalgesic area could be mapped out round the chest at the level of the fourth interspace. The tenderness was most evident on rubbing over the sternum. Vibrations of a large tuning-fork (C=128 per second) could not be appreciated below the ninth rib. There was complete loss of all other forms of sensation below the sixth rib.

Vasomotor and trophic changes.—The legs were not swollen. There was no sweating of any part of the body. The abdomen was distended with gas. There was a bed-sore about the size of a five-shilling piece (about 5 cm. in diameter) over the upper part of the sacrum in the mid-line. Though superficial, it was septic and was covered in parts with black sloughs.

Sphincters.—Complete retention of urine. Catheter passed six-hourly, and the bladder washed out with eusol, 1 in 16,000, night and morning.

The anal sphincter muscle was tonic.

Condition on August 28, 1916 (*Twenty-two Days after the Injury*).

Motion.—The muscles of the legs and abdomen were flaccid. No involuntary movements observed.

Reflexes.—Knee-jerks, ankle-jerks, and abdominal reflexes absent. For the first time on scratching the soles of the feet upward movements of the toes were noticed. Hamstring contraction had not been obtained previously on plantar stimulation; yet with the first appearance of toe movement tightening

of the hamstring tendons could be felt, and contraction of the anterior tibial group of muscles also appeared. The reflex was more easily obtained from the right than the left leg. The "receptive field" for this reflex was limited to the soles of the feet, and the threshold was lowest on the outer parts. When one sole was scratched and a flexion reflex in that leg evoked, no contraction of the extensor muscles of the other leg could be seen or felt. Cremasteric and bulbo-cavernosus reflexes were not elicited.

Sensation.—He complained of a dull, localized pain over the sixth dorsal vertebra where the bullet was situated, and said he felt "as if I were lying on the bullet."

On testing sensation the findings were similar to those recorded on August 17, 1916.

Vasomotor and trophic changes.—He declared that the left side of neck and the left shoulder down to about the third interspace, and left arm and hand, were frequently damp from sweating. On testing, the left face and arm were certainly damp. The skin of the right arm and face and of the trunk below the fifth rib was dry.

The bed-sore was now much cleaner.

Sphincters.—Retention was not complete. The patient passed a little urine reflexly on one or two occasions. The sphincter ani was tonic.

Urine: Acid, sp. gr. 1012, trace of albumin (cold nitric acid test), no pus, slight deposit of mucus and phosphates.

Condition on August 31 (*Twenty-five Days after the Injury*).

Motion.—Periodic upgoing toe movements with tightening of the tibialis anticus and hamstring tendons were observed. The movements were never seen in both legs at the same time. Usually the physiological flexors of one leg contracted, then those of the other: though sometimes the right leg, which was the more active, would give a few jerks before the left leg moved.

Reflexes.—On briskly tapping the right patellar tendon contraction of the quadriceps muscle, chiefly the vasti, was produced and the slack tendon was seen to tighten momentarily. This contraction, however, was not sufficient to move the leg as a whole. This response was not obtained in the left leg. Ankle-jerks, abdominal, cremasteric and bulbo-cavernosus reflexes were absent. On scratching the sole of the foot with a pin, fairly brisk upgoing toe-movement was evoked with contraction of the dorsiflexors of the foot, of the flexors of the knee and hip, and of the adductors of the thigh. The only parts which changed posture were the toes, whilst the position of the lower extremity remained stationary. The response was strictly confined to the stimulated leg. It was perhaps more easily obtained in the right lower limb. The contractions were evoked only by nociceptive stimuli—*e.g.*, pin-pricks, scratching with a pin, pulling hairs, or squeezing the muscles or the bones. The reflexogenous area extended from the sole to about the junction of the lower and middle thirds of the leg below the knee. The threshold was lowest in the sole and increased with the distance of the part stimulated from the sole.

Sensation.—He could not feel the catheter being inserted nor an enema being given. He had no girdle sensation at the level of the lesion and had no pain. As a rule when he closed his eyes he had the feeling that his body ended about the sixth rib.

Sphincters.—Periodic micturition was more frequent and more urine was being voided at a time. No dribbling. The anal sphincter was tonic. Fæces were evacuated more briskly, showing that the muscle of the rectal wall was contracting.

Condition on September 3 (Twenty-eight Days after the Injury).

Situation of the bullet confirmed by X-ray examination. Urine: acid, slight trace of albumin, no pus. Bacillus proteus isolated. Bed-sore showed signs of healing.

Condition on September 6 (Thirty-one Days after the Injury).

Motion.—The involuntary contractions of the physiological flexors of the lower limbs were sufficiently strong to cause slight flexion at hip and knee, dorsiflexion at ankle and upward movement of the toes The lower extremities never moved together. Flexion of one leg was occasionally followed by flexion of the other. Sometimes when one limb was flexing the knee extensors of the other could be felt to contract feebly. The right lower extremity was the more active. The muscles were less flaccid between the jerks. Wasting of the legs could not be detected.

Reflexes.—On sharply tapping the patellar tendon of either lower limb the tendon could be seen to tighten and the quadriceps muscle to contract. The contraction however was still too weak to produce extension of the leg on the thigh, i.e., there was no leg-jerk. One got the impression that the muscle used up all its activity in taking up slack; nothing was left for actual movement of the limb. The response in the right lower extremity was brisker and stronger than in the left. The tendon relaxed very quickly after being momentarily tightened.

No contraction of the calf-muscles occurred on tapping the tendo Achillis of either leg. Abdominal reflexes were absent. Flexion movements at the joints were evoked by nociceptive stimulation. The receptive area for the reflex had extended to the groin. The response was more brisk in the right than in the left lower limb. The movement was sluggish in onset, attaining its height after the stimulus (pin prick) had been removed and was of short duration. The extension of the limb which followed the flexion seemed to be due to gravity alone and not to active contraction of the extensor muscles, for contraction of these could neither be seen nor felt. To elicit a crossed extension reflex with ipsilateral flexion, either a strong stimulus or repeated slighter stimuli were required. The stimulus had to be stronger than that necessary to produce a simple flexion reflex. The contralateral extensors could not as a rule be seen to contract, but the contractions, particularly of the quadriceps muscle, could be distinctly felt. Active extension of the limb was

not observed. When a flexion reflex was evoked by a strong stimulus (scratching the sole with the point of a pin) sometimes the rectus abdominis of the same side could be distinctly seen to contract. This response was obtained by stimulating either sole, but it was strictly ipsilateral.

Sphincters. — The bladder evacuated more urine with each contraction. Sphincter ani was tonic and contracted on the finger. Enemata were not required. The patient obtained an action of the bowels with Ext. casc. sagr. liq. 2 dr. every second night. Bed-sore was healing.

Operation on September 8 (Thirty-three Days after the Injury).

Under general anæsthesia, Mr. Walton removed the laminæ of the sixth dorsal vertebra with a 1-inch trephine after detaching the spinous processes of the fourth, fifth and sixth with forceps. The laminæ of the fifth and fourth were cut through with forceps. The dura was opened. Opposite the bodies of the fifth and sixth vertebræ the cord was found to be completely divided and the ends separated by about an inch (2·5 cm.). An aneurysm needle was passed round the canal to corroborate the appearance of complete separation. A shrapnel bullet was found embedded in the body of the sixth vertebra and was easily removed. It was just over 1 cm. in diameter, and had one side flattened. The wound was closed in the ordinary way and a tube left in under the flap, to be removed in twenty-four hours. The patient stood the operation well.

Condition on September 9 (Thirty-four Days after the Injury).

Tube was removed from the wound, which was looking well.

Motion.—Flexor spasms more brisk than before the operation. The lower extremities were never seen to flex together. As a rule one went into spasm as the other was relaxing, though occasionally the right lower limb, which was still the more active, flexed once or twice while the left remained passively extended on the bed. The muscles of the lower extremities, particularly the physiological flexors, showed more tone between the spasms. The muscles in spasm were hypertonic. There was no appreciable wasting of the muscles of either limb.

Reflexes.—On tapping the patellar tendon there was distinct contraction of the quadriceps muscle but no actual movement of the limb. The response was more easily evoked from the right than from the left leg, and had the same characters as when last noted.

Ankle-jerks: Right doubtfully present, left absent.

Abdominal reflexes: (1) By scratching with a pin the skin over the rectus abdominis, a fairly quick contraction of the muscle was evoked. The oblique muscle did not contract. The response was unilateral so long as the point stimulated was not close to the middle-line, but both recti contracted distinctly when the skin over the linea alba was scratched. The convex abdominal wall was flattened. This reflex was obtained only in the lower segments.

(2) When, however, the skin external to the rectus was scratched, a slow late contraction of the oblique muscle was evoked. The contraction was localized under the part stimulated, and it followed the line of the external oblique fibres, *i.e.*, outwards and upwards. The rectus remained quiescent. The response was obtained by stimulating any part of the skin over the oblique muscles and on either side, but it was more facile in the lower than in the upper abdominal wall. It was not crossed. The contractions were slower, lasted longer, and were more delayed than the normal abdominal reflexes.

Cremasteric reflexes: On scratching the inner surface of the thigh near the perineum a slow deliberate contraction of the dartos of that side was evoked and the testicle was pulled up. A response was got from either side.

Bulbo-cavernosus reflex: Distinct contraction of the bulb could be felt on pricking either half of the glans penis.

Flexion reflexes: The reflexogenous area extended from the foot nearly to the top of the thigh. The most receptive part of the field was the sole, and its outer half perhaps more than its inner half. Stimulation by pricking, scratching, or squeezing any part of the receptive field produced flexion at the hip, adduction of the thigh, flexion at the knee, dorsiflexion at the ankle, upgoing toes and fanning of the four outer toes. Along with this response in the ipsilateral limb, tone was evoked in the extensors of the contralateral limb, as evidenced by the tightening of the quadriceps cruris and calf muscles unless the stimulus was weak. Sometimes the change in form of the extensors could be seen, but as a rule it could only be felt. The crossed extension reflex was elicited by stimulation of either lower limb, but with more ease and certainty by stimulation of the right. The right leg was altogether more active reflexly than the left. I failed to obtain ipsilateral extension by stimulation of any part of either limb or of the inguinal or perineal regions.

Sphincters.—Reflex evacuation of the bladder was more frequent and the residual urine was less. The evacuations were becoming more regular in time.

Condition on September 15 (*Forty Days after the Injury*).

Stitches removed: surgical and entry wounds quite healed.

Motion.—Involuntary flexor spasms were more frequent. The movements were of wider range.

Reflexes.—It was still doubtful whether the ankle-jerks were present.

Trophic changes.—All the slough had gone from the bed-sore but there was still some discharge from it.

Condition on September 20 (*Forty-five Days after the Injury*).

General condition excellent.

Motion.—Both lower extremities were very active, the involuntary flexor spasms being stronger and recurring at shorter intervals. The lower limbs

never flexed together and so far as I could make out actual extension of one leg did not occur with flexion of the other, though the extensors could be felt to be contracting. Usually the limbs were in spasm alternately, though sometimes the right leg gave two or three short, quick jerks before the left leg moved. The straightening out of the leg which followed the flexion was a pure passive extension, a response to gravity. I was quite certain that it was not of the nature of a thrust. The abdominal or back muscles were not involved in the spasms.

Tone of the muscles: (*a*) Between the spasms. The physiological flexors had distinct tone, though not the tone of the normal muscle under cerebral control. They had a good shape unlike the physiological extensors (quadriceps cruris and calf muscles), which were undoubtedly flabby.

(*b*) During a spasm. The muscles in front of the leg and the hamstrings were hypertonic, while the calf muscles and the extensors of the knee remained flabby and soft. No appreciable wasting of the muscles could be made out.

Reflexes.—Quadriceps contraction on tapping the patellar tendon was more brisk and greater in the right leg than in the left. Extension of the knee, however, was still absent.

Contraction of the calf muscles was elicited on either side by tapping the tendo Achillis, right brisker than left. No ankle clonus.

Abdominals: The contractions of the abdominal muscles which followed nociceptive stimulation had the same characteristics as before except that on scratching the skin over the rectus of one side both recti sometimes contracted together so that the abdominal wall was rendered flat. When the recti were contracting the lower limbs did not move. The abdominal reflexes were elicited only from the lower segments.

Cremasteric and bulbo-cavernosus reflexes were obtained.

A complete flexion reflex could be evoked by stimuli of less intensity—e.g., rubbing the soles; but this stimulus was not potent for any other part of the reflexogenous area. The threshold increased with the distance of the part stimulated from the sole. A crossed extension reflex was fairly constant but the contractions of the extensor muscles could be made out only by palpation. Sometimes contraction of the ipsilateral rectus abdominis accompanied the reflex. The right lower extremity was more active than the left. Upgoing movement of the toes always formed part of a complete flexion reflex. The "extensor" plantar reflex never occurred alone. The movement of the lower limb in response to a stimulus was not alternating. A steady flexion occurred at all joints which lasted as long as the brief stimulus was applied. When the pin was removed the leg simply fell straight. The extension was not due to contraction of the extensor muscles so far as I could make out. The most efficient stimulus was a nocuous one—e.g., pin-prick, scratching or squeezing—though sometimes a reflex could be evoked by rubbing the sole of the foot. The reflex was always somewhat sluggish in onset and it usually attained its height just after the brief stimulus (pin-prick) was removed. The situation of the stimulus affected to a certain extent the reflex

action. If the outer part of the sole was pricked there was a tendency to eversion of the foot with dorsiflexion at the ankle. On the other hand, when the inner edge of the sole was stimulated inversion was associated with dorsiflexion.

Sensation.—The only abdominal sensations he experienced were localized in the upper epigastric region. They were feelings of distension. When given a griping purge, he felt some discomfort in the epigastrium which disappeared rapidly. He could not with any exactness locate his discomfort. If his abdomen was distended with gas the only discomfort he had was over the stomach. He was conscious of deep pressure by hand on the abdomen over the same limited area.

Sphincters.—Reflex evacuation of the bladder as before. Sphincter ani tonic.

Urine: Acid, slight trace of albumin, no pus or deposit. Bacillus proteus.

Vasomotor and trophic changes.—He had been sweating less on the left face, arm, and chest, but the weather had been cooler. The skin below the level of the lesion was damp for the first time. He had no temperature. The bed-sore was cleaning up and granulating.

Condition on October 2 (Fifty-seven Days after the Injury).

Motion.—The spasms of the lower extremities were not more frequent nor more intense, nor had they changed in character. No wasting of the muscles. The tone of the flexor muscles while in the resting state was, I thought, a little greater. The extensor muscles were not toneless. They were not so flabby, nor did they flatten out so much when the lower limbs were resting on the bed, but their tone was distinctly below that of the physiological flexors.

Reflexes.—A weak stimulus applied to the sole evoked a big withdrawing movement. Associated with the flexion of one limb, contraction of the extensors of the other limb could usually be felt, and sometimes seen. The flexion response to application of the stimulus was not instantaneous. The maximum movement occurred after the stimulus was removed, if the stimulus was a single quick pin-prick. If the stimulus was continued, the flexed limb wavered only slightly. The subsequent extension was slow, and gave one the impression that the limb was answering to gravity rather than that active contraction of the extensor muscles had taken place.

Knee-jerks: When the patellar tendon was tapped, the leg extended at the knee, whereas, before, there was merely contraction of the quadriceps muscle and tightening of the patellar tendon. The right leg moved more than the left. Relaxation was sudden.

Achillis jerks: On tapping the tendo Achillis, there was brisker contraction of the calf muscles. The right leg was more active than the left.

Ankle clonus of short duration—four or five irregular jerks—could be elicited on the right side, not on the left.

Both forms of abdominal reflex were more difficult to evoke on this date. Their characteristics had not altered.

Sensation.—The irregular hyperalgesic band round the chest had given place to a feeling of tightness about the level of the fifth interspace.

He obtained no abdominal sensations except from the epigastrium. The sensations from that region were of something solid inside. They were noticeable after food, and when he took a deep breath. He declared that sometimes he had a feeling that the hamstring tendons were aching as after a climb. He imagined, too, that he had tingling sensations from the legs at times.

Sphincters.—Automatic expulsion of urine was occurring about every two hours, though none might be passed for several hours. Rarely small quantities of urine were expelled at short intervals. On swabbing the penis preparatory to passing the catheter, there was frequently expulsion of some urine. The catheter was being passed every six hours, and the bladder was washed out night and morning with eusol 1 in 16,000. He was taking urotropin gr. x three times a day.

Sphincter ani was tonic. On pricking the skin of the buttocks, contraction of the anal sphincter occurred.

Condition on October 6 (Sixty-one Days after the Injury).

Motion.—Involuntary movements of the lower limbs were occurring with the same frequency. Fibrillary twitching of the anterior tibial muscles was noticed.

Reflexes.—A flexion reflex was obtained by stimulating any part of either limb up to the groin. The threshold was much lower in the sole than in any other part of the reflexogenous area, the strength of the stimulus having to be gradually increased as the groin was approached. There, repeated slight scratching or a fairly strong pinching stimulus was necessary to produce the reflex. The stimulus had to be stronger in the left than in the right leg. Crossed extension usually accompanied an induced or an involuntary flexion reflex of the other leg, except when a minimal stimulus was applied. The extensor cruris muscles could usually be seen to contract, but extension of the leg could not be seen. If the stimulus was strong, the rectus abdominis of the same side was involved in the reflex, so that the patient was bent forwards and towards the flexing limb.

Sensation.—No visceral sensations below the epigastrium.

Vasomotor changes.—Sweating of the left face, neck and shoulder had not been noticed for some days. On the other hand, the skin of the palms of the hands, of the trunk below the fifth rib or the fourth interspace and of the legs was distinctly moist.

Condition on October 7 (Sixty-two Days after the Injury).

Right ankle clonus was obtained, about six jerks of unequal amplitude. It was absent on the left side.

Condition on October 12 (*Sixty-seven Days after the Injury*).

General condition of the patient was excellent.

Motion.—The involuntary spasms of the lower extremities were more vigorous though not more frequent. Sometimes for about five minutes the limbs flexed alternately, while at other times the right limb flexed several times in succession at short intervals, each flexion being accompanied with palpable contraction of the extensor muscles of the other leg. The lower extremities have never flexed together. Sometimes both were quiescent for about a quarter of an hour.

In the resting state, the tone of the physiological flexors was below normal. The tone of the extensors was considerably less than that of the flexors, though the muscles were not toneless. If there was any wasting of the muscles of the legs it was very slight.

Reflexes.—Flexion reflexes were easily elicited, and flexion of one lower limb was accompanied by active contraction of the extensors of the other. The altered form of the extensors was not sufficiently great to be seen. It could always be felt.

Strong stimulation (repeated scratching) of the skin over one rectus abdominis induced not only contraction of the underlying rectus muscle but often evoked with it a complete flexion reflex of the ipsilateral leg. When the abdominal skin was scratched in the middle-line, both recti contracted and both lower extremities flexed. This complete response was not, however, always obtained. The application of a strong nocuous stimulus to the sole evoked, with the usual flexion reflex of that limb, a contraction of the ipsilateral rectus abdominis. This response was obtained on both sides.

Two types of abdominal reflexes were evoked by nocuous stimulation of the abdominal wall :—

(1) On pricking or scratching the skin over the external oblique muscle, a localized contraction was obtained which involved the oblique muscles only and followed the course of the external oblique fibres. The rectus did not contract. The contraction was rather delayed, and occurred immediately round the stimulated point. It was not sufficient to move the patient, and the legs were not involved. The reflex was never crossed.

(2) To a pin-prick of the skin over the rectus, that muscle contracted and sometimes also the muscle of the other side, though to a lesser degree. Sometimes the ipsilateral lower limb flexed, and if the skin in the middle-line was scratched both recti contracted, so that the abdominal wall flattened in the centre and bulged out at the sides, and both lower extremities flexed. The oblique muscle did not contract unless the pin was dragged along the skin above the rectus on to the skin above the external oblique.

Both reflexes were obtained below the umbilicus, and for a short distance above it. Knee-jerks and ankle-jerks were brisk, the right more so than left. Ankle clonus was obtained on the right side but not on the left. Cremasteric reflexes were easily elicited both sides. Bulbo-cavernosus reflex was obtained

by pricking either side of the glans penis. The contraction was strong. On scratching the inner surface of either thigh near the perineum the penis hardened, but complete erection was not induced. Priapism had been more frequent, sometimes accompanied by emissions.

Sensation.—Vibrations of a tuning-fork (C = 128 per second) were not appreciated below the eighth dorsal spine or the ninth rib.

Sphincters.—The bladder during the previous day had passed hardly any urine reflexly. A catheter was passed thrice daily, and the bladder washed out night and morning. He had required an aperient every fifth day. No enemata. A motion was now passed daily.

Condition on October 26 (Eighty-one Days after the Injury).

The patient had been putting on flesh and had been sleeping very well. His general condition was excellent.

Motion.—Flexor spasms had become very frequent since last note was made, and had been more noticeable especially in the left lower limb. Their activity varied on different days. The abdominal recti were more involved in the leg spasms than they had been before. The movements of the lower extremities were more extensive. The knees jumped higher.

Reflexes.—Knee-jerks and ankle-jerks were increased and equal. There was good extension of the leg at the knee when the patellar tendon was tapped, but not I thought sufficient to correspond with the contraction of the quadriceps. I always got the impression that the muscle was "taking up slack." A poorly sustained ankle clonus was obtained from the right leg consisting of six or eight jerks; none from the left leg. Plantars were "extensor" as before, and the response could not be obtained apart from the general flexion reflex of the lower limb. Flexion reflexes were elicited by slight stimuli—e.g., stroking the sole or lifting off the bedclothes. The limbs never flexed together, and there was always an increase in tone of the contralateral extensors accompanying flexion of the stimulated limb. Any movement of the upper part of the body—e.g., raising himself in the bed by the pulley—brought on the spasms.

The two types of abdominal reflexes were obtained by stimulation, but with perhaps less ease than when last tested. Still they were distinctly present.

Cremasteric and bulbo-cavernosus reflexes were present.

Priapism had been fairly frequent. Erection came on when he was turned on his side or moved much or when the penis was handled. It never occurred however when the catheter was being passed. Stiffening of the penis was caused by scratching the inner surface of either thigh.

Sphincters.—The bladder was reflexly voiding about 2 oz. of urine at a time. There had never been any dribbling. The catheter was passed three times a day and the residual urine was diminishing in amount. The bladder was washed out night and morning with 1 in 16,000 eusol.

Urine: Acid, slight trace of albumin; no pus, B. proteus.

The bowels were emptying themselves actively daily. An aperient given twice a week was the only help required. The anal sphincter contracted on the finger.

Condition on October 28 (Eighty-three Days after the Injury).

Motion.—Involuntary spasms of the lower extremities were frequent. There was no appreciable wasting of the muscles of the limbs. During a flexor spasm there was undoubtedly heightened tone in the physiological flexors and hypotonia in the extensors of the same limb. In the crossed limb during the reflex there was increased tone in the extensors, though less than in the flexors of the stimulated limb. Between the spasms—i.e., when the legs were lying extended and quiescent—it was very difficult to estimate the condition of the muscles as regards tone, the legs were so irritable. The extensors, e.g., the calf muscles, were rather flabby, and were flattened out by the weight of the limb more than are normal muscles. Yet they were much less flabby and shapeless than they were a few weeks before. Extension of the leg in response to a sharp tap on the patellar tendon was considerably longer delayed than is normal. The slack of the tendon had to be taken up before the muscle had shortened enough to move the leg. This was even more striking in the earlier stage of slight reflex activity in the extensors. As noted on August 31, on tapping the patellar tendon the contraction of the quadriceps muscle was sufficient only to tighten the loose tendon for a moment and no movement of the leg occurred. The tendon relaxed very quickly. There was undoubtedly, I thought, more tone in the flexor group of muscles than in the extensor group both when the limbs were quiescent and when in spasm.

Reflexes.—The reflex activity of the lower extremities had not altered, and all the reflexes previously described were easily elicited.

Sensation.—He did not complain of a tight feeling round the chest nor of pain on rubbing the skin. He had no abdominal sensations after food apart from "solid feelings" in the epigastrium. The epigastric sensations however continued very definite, though difficult to localize exactly, and they were always in evidence after food. As before, a griping purge gave rise to no sensation, except almost immediately after it was taken, when he complained of the old uncomfortable feeling of distension in the epigastrium, somewhere about the level of the eighth costal cartilages. He did not know that my hand was being pressed heavily on the abdomen below the umbilicus or just above it when his eyes were shut. He said that the skin of the upper part of his chest was being pulled on.

Vasomotor changes.—When warm he sweated only occasionally on the left face, arm and neck, but the palms of his hands were always damp. The left hand was always colder than the right.

Temperature taken at right axilla, 96·5° F.; temperature taken at left

axilla, 95·8° F. The skin below the fourth interspace was always slightly moist. Slight scratching or handling of the skin of the paralysed parts was always followed by erythema.

Condition on November 4 (*Ninety Days after the Injury*).

Motion.—The reflex spasms of the lower extremities were, if anything, more frequent in the right than in the left leg. Though one big jump was the usual phenomenon, sometimes two or three small jumps occurred in rapid succession. The invariable involuntary movement was flexion at the hip, adduction of the thigh, flexion at the knee, dorsiflexion at the ankle and upgoing toes, with fanning of the four outer toes. Usually there was an accompanying contraction of the quadriceps cruris and the calf muscles of the opposite leg. The ipsilateral rectus abdominis participated more often than formerly in the flexor spasm, so that as the leg flexed the patient was pulled forward and to the side. The involuntary spasm might start in the abdominal rectus of one side and spread to the leg of the same side. The right rectus was the more active just as the right leg was. The oblique muscles of the abdominal wall had not been known to take part in the spasms, nor had I seen both abdominal recti contract at the same time.

Reflexes.—Flexion reflexes were easily elicited. Rubbing of one sole produced a slight but complete response, but the most adequate stimulus and the only one applicable to the upper part of the reflexogenous area was a nocuous one. The reflex which resulted from stroking the sole was not usually accompanied by contraction of the contralateral extensors, whereas a a crossed response invariably accompanied a flexion reflex which had been evoked by a nocuous stimulus. Bilateral flexion of the legs and simultaneous contraction of both abdominal recti could be obtained by:—

(1) Pricking the perineum in the mid-line between the upper part of the thighs.

(2) Squeezing the glans penis or by pulling the prepuce over it.

(3) Scratching the abdominal wall in the mid-line between the umbilicus and pubis.

(4) The automatic expulsion of urine by the bladder.

(5) The reflex emptying of the rectum when an enema had been given.

These stimuli also increased the sweating of the palms of the hands and of the skin below the fourth interspace.

I could not satisfy myself that contraction of the crossed extensors occurred when one leg was passively flexed.

Knee-jerks were brisk and equal. Ankle-jerks were brisk and equal. Definite ankle clonus (six or eight jerks) was obtained on both sides, but more easily on the right. Both types of abdominal reflexes were easily elicited below the umbilicus. If the stimulus producing the rectus contraction was strong the ipsilateral lower limb nearly always flexed. Cremasteric and bulbo-cavernosus reflexes were obtained by the usual methods of stimulation.

By rubbing the inner surface of either thigh stiffeneng of the penis was produced. Scratching with a pin evoked erection of the penis and flexion of the lower limb. Erections were stronger and more frequent when he was turned on his side. He declared that they never occurred when he was lying on his back except when the genitals were touched. Emissions were common. He had one nearly every morning.

Vasomotor changes.—He sweated profusely below the fourth interspace and in the palms of the hands. It was more profuse than it had ever been.

Sphincters.—Automatic evacuation of urine. Residuum less. Bladder emptied twice daily by catheter. Bowels were moving every day. Aperient twice a week. Enemata not required.

Condition on November 12 (*Ninety-eight Days after the Injury*).

The patient complained that he felt seedy. Temperature 99·6° F. [37·5° C.] and pulse 112.

Condition on November 15 (101 *Days after the Injury*).

Temperature 100·4° F. [38° C.] No cough or evidence of cystitis.

Motion.—The involuntary spasms were few. The limbs for fairly long periods lay quiescent.

Reflexes.—All the reflexes were more difficult to evoke. Stronger stimuli were necessary, and the motor field of response was more limited—e.g., on scratching the foot contraction of the crossed extensors and of the ipsilateral abdominal rectus did not so often accompany flexion of the stimulated limb.

Sensation.—He had no abdominal discomfort.

Vasomotor changes.—The palms and the skin below the fourth interspace sweated profusely and the skin of the rest of the body was damp.

Sphincters.—The bladder activity did not seem to be affected and the sphincter ani was tonic.

Condition on November 27 (113 *Days after the Injury*).

He had quite recovered. Temperature had been normal for five days.

Motion.—The reflex activity of the lower extremities was still less than it was before he got the chill. The legs remained at rest for longer periods and the abdominal recti were not so often involved in the spasms. The tone of the muscles was perhaps a little less. If there was any wasting it was slight and not more than could be explained by disuse.

Reflexes.—The reflexogenous area for the flexion reflex had contracted a little from the top of the thigh in both legs. The same types of stimuli brought on the reflex, but their threshold value was increased. The response was less vigorous, though the same muscles were involved and each reflex was complete. But the ease with which all the reflexes could be evoked had diminished, and the abdominal recti did not take part in the flexion reflex so often as formerly. Removing of the bedclothes was not so apt to cause the legs to fall into spasm or the recti abdominis to contract.

All the reflexes were obtained, but not so easily as before.

Sensation.—Abdominal sensations of discomfort after food were fairly frequent and were indefinitely localized in the epigastrium. The abdomen was more distended than it had been before he had the attack, and his discomfort was greater. He felt nothing when an enema was given or when a griping purge was administered, except in the latter case for a feeling of distension below the ensiform.

Vasomotor and trophic changes.—He was sweating from the feet to the fifth rib and in the palms, though not very profusely.

The bed-sore had practically healed.

Condition on December 28 (144 *Days after the Injury*).

The patient had been getting up in a chair for a short time every day for the previous month. The legs had been gradually let down and after the first few days they had swelled very little. He was feeling out of sorts and had vomited three times in the night. He had slight diarrhœa and was very flatulent. He had enjoyed himself too well on Christmas Day in the matter of food.

Motion.—The leg spasms were frequent and very vigorous. They were again as brisk as ever, and the left leg was as active as the right. Flexion of one leg was always accompanied by contraction of the extensors of the other, though the contralateral leg did not visibly extend. Sometimes the legs flexed alternately, one big jump each. Most often, however, two or more flexion movements of one leg occurred in quick succession before the other leg moved. Since the day before, when the digestive disturbance began, he had had frequent spasms of the muscles of the abdominal wall and of the back, unaccompanied by leg movements. At other times a spasm began in the one abdominal rectus, spread to the back muscles of the same side and down the ipsilateral leg. When he coughed the spasm involved both recti, and one or both legs. The legs flexed together only when the spasm originated in the abdominal wall. The oblique muscles did not take part in the spasm, though they may have done when he coughed.

Strong stimuli were necessary to elicit a flexion reflex from the upper part of the thigh.

Knee-jerks were plus and equal. Ankle-jerks plus and equal but not so brisk as the knee-jerks. A few clonic jerks could be obtained at both ankles, but the clonus was not sustained. Both types of abdominal reflexes could be evoked with ease. Cremasteric and bulbo-cavernosus reflexes were present. He had been getting erections but not so often as formerly. It was possible to cause the penis to stiffen by scratching the inner surface of the thighs. Emissions had been of rare occurrence during the previous month.

Vasomotor changes.—Sometimes he sweated only from the knees to the feet, sometimes from the thighs to the feet and sometimes from about the fifth rib to the navel, when it was a cold sweat and associated with uncomfortable feelings of distension in the epigastrium. Sometimes the whole body below the fifth rib poured with sweat. The palms of the hands were always damp.

The face, neck, arms and upper part of the chest were dry. Being put back to bed started the sweating; also sometimes the passage of a catheter and the administration of an enema. He rarely sweated when he was sitting up in a chair. The left hand was colder than the right.

Condition on January 1 (148 *Days after the Injury*).

The patient had quite recovered and was getting up again.

Motion.—The involuntary movements of the legs were as frequent as ever. The muscles of the abdomen and limbs had recovered their old activity. Only slight wasting of the leg muscles could be made out and it was greater in the extensors than in the flexors.

Reflexes.—The reflexogenous areas for the flexion reflex reached the upper part of the thighs and the reflexes were very facile. The threshold was lowest in the soles. The ipsilateral rectus abdominis nearly always contracted as the leg flexed. The other reflexes were easily evoked.

Sensation.—The tight feeling round the chest had returned, but its position had altered from about the fifth rib to the level of the ensiform, about 3 in. lower down.

Condition on January 11 (158 *Days after the Injury*).

Bladder.—The following observations were made in conjunction with Dr. Head. Two minutes before the catheter was inserted the patient passed automatically 110 c.c. of urine as soon as the swab with antiseptic fluid was placed on the glans penis. Catheter passed. Residual, 340 c.c. of urine.

(1) On pouring into the bladder through the catheter a solution of eusol 1 in 16,000 in water, he evacuated at 650 c.c. He passed 610 c.c. No more could be recovered by pressure.

(2) More fluid was poured in. He evacuated at 600 c.c. Amount evacuated, 595 c.c. Nothing recovered by pressure.

(3) More fluid was poured into the bladder. He evacuated at just short of 600 c.c. Amount evacuated, 590 c.c. Nothing recovered by pressure.

Throughout this observation he was astonishingly accurate. From the beginning the column of fluid in the tube which was connected to the catheter showed oscillations which proved to be respiratory. On asking the patient to stop breathing they ceased. But after about 400 to 500 c.c. of fluid had entered the bladder, a bigger oscillation began which culminated in the backflow.

About 300 c.c. were evacuated at once. Then came a pause, followed by a further passage of 200 c.c., then another pause and so on. If the tube, now empty, was held erect each of these renewed flowings could be seen to cause a very definite rising in the tube. The mouth of the tube when turned was never allowed to fall below the level of the abdominal wall so as to syphon.

Throughout the observation he was unconscious of any manipulation or passage of fluid. He was asked not to try and press with his abdomen and did not do so.

Urine: Acid, no albumin, no deposit of pus, slightly cloudy.

Faradic reactions of the leg muscles.—Left leg: No response to faradism in any of the muscles. Right leg: Vasti and the muscles below the knee gave good contractions to a strong current.

Galvanic reactions.—Left leg: All muscles gave brisk contractions to a current of 20 m.a. Right leg: The muscles reacted well to a current of less strength than did those of the left leg.

Condition on February 5 (183 *Days after the Injury*).

On the previous day he had complained of headache and of feeling seedy. Temperature rose to 103·6° F., and there was more tone in the right abdominal rectus than in the left. Loss of appetite but no vomiting.

Motion.—The involuntary movements of the legs were active and the abdominal recti were frequently implicated. When the spasms began in the abdominal wall both legs often jumped together.

Reflexes.—Flexion reflex in both legs was very easily obtained and the reflexogenous area extended to the groin. The ipsilateral abdominal rectus contracted as one limb flexed in response to a stimulus. Knee-jerks were plus and equal. Ankle-jerks present and equal. Ankle clonus absent both sides. Both types of abdominal reflexes were easily elicited. Cremasterics and bulbo-cavernosus reflexes were present.

Sensation.—He complained of more abdominal discomfort and of feelings of pressure which he referred vaguely to the epigastrium. He did not feel deep palpation of the kidneys.

Sphincters.—Reflex evacuation of urine as before. The total amount of urine passed in the 24 hours was slightly less than usual. Catheter passed night and morning. Residuum was slightly increased in amount.

Urine: Acid, trace of albumin, no deposit of pus, deposit of phosphates.

Sphincter ani tonic.

Condition on February 12 (190 *Days after the Injury*).

Temperature 103° F., [39·5° C.] pulse 100. The temperature had kept up since February 4. He felt very seedy, had vomited several times, had no appetite, and was constipated. He had undoubtedly an attack of pyelitis. The right abdominal rectus was more rigid than the left.

Motion.—The flexor spasms of the legs were fewer and there were longer intervals between them. The abdominal recti frequently fell into spasm by themselves without the legs flexing.

Reflexes.—The reflexogenous area for the flexion reflex was smaller and reached only the junction of the middle and upper thirds of thigh on both legs. The reflex could not be evoked by rubbing the soles of the feet. Crossed extension was never elicited. Both types of abdominal reflexes were obtained, but the threshold was higher. Knee-jerks and ankle-jerks were present but less brisk than usual. Ankle clonus was not elicited from either leg. Cremasterics and bulbo-cavernosus were present.

Since the attack began he had had neither erections nor emissions.

The reflex activity of the legs and abdomen was undoubtedly lowered.

Sensation.—He complained of discomfort in the abdomen, but he could not refer the sensations to any particular part. Sometimes he thought that a weight was pressing on the stomach region and at other times he referred these pressure feelings to the hypogastrium.

Vasomotor and trophic changes.—The whole skin was usually damp and during the night he sweated very freely. He always sweated more from the palms of the hands and from the skin below the fourth rib, than from the skin of the rest of the body. So profuse was the sweating that the drawsheet had to be changed sometimes as often as five or six times a day. The skin of the upper part of the sacrum was red and inflamed and a small patch in the centre about the size of a shilling was black.

Sphincters.—The amount of urine the bladder was automatically voiding in the twenty-four hours was distinctly less than before the attack. Sphincter ani was tonic.

Condition on February 26 (204 *Days after the Injury*).

The patient was feeling very much better, the sickness had gone and his appetite was returning. Temperature 98·6° F. [37·6° C.] and pulse 60. The right abdominal rectus was still more rigid than the left.

Motion.—The involuntary flexion movements of the legs were considerably less frequent than they were prior to the attack. The excursion of movement in each spasm was less. The knees did not jump so high. The general rule was that one leg flexed alone and the abdominal recti remained quiescent or one or both recti contracted without the legs moving. The tone of flexors and extensors was diminished. The legs had wasted very little.

Reflexes.—All the reflexes were evoked but stronger stimuli were required.

Sensation.—The uncomfortable feelings in the abdomen had ceased, though the abdomen was still distended. Any sensations he had after food were referred to the epigastric region.

Vasomotor and trophic changes.—He was sweating profusely from the palms and from the skin below the fourth rib, but the rest of his skin was dry. A deep bedsore 3 in. by 2 in. was situated over the upper part of the sacrum. Its base was covered with black sloughs and the edge of the skin was undermined.

Sphincters.—The total amount of urine excreted in the twenty-four hours had increased just as had the amount voided automatically by the bladder.

Urine: Acid, trace of albumin, no deposit of pus and bacilli. Cultures: *B. coli* mainly, also *B. proteus*.

Condition on April 22 (259 *Days after the Injury*).

Since the last note the patient had been very fit, and had no rise of temperature. Vaccine of *B. coli* and *B. proteus* was given hypodermically in weekly doses.

Motion.—Involuntary movements of the legs were as frequent as ever. Each spasm was a complete flexion reflex and was associated with contraction of the ipsilateral rectus abdominis and of the quadriceps cruris and the calf muscles of the contralateral leg. The legs never jumped together unless the skin of the perineum or the external genitals was touched. One leg was not regularly more active than the other. On one day the right leg might jump more often than the left and the next day movement of the left might be more frequent than of the right. Should he try to raise himself in the chair with his arms to get for example a cushion put under him, both legs would flex so quickly and vigorously with simultaneous contraction of the abdominal recti that he would be shot forward in the chair or even out of it. Erection of the penis always brought on bilateral flexor spasms, but the most violent ones occurred immediately after being taken out of his bath. A strong stimulus was a sudden change of temperature.

The muscles of the back went into spasm with the physiological leg extensors (quadriceps and calf muscles) while the abdominal recti and sometimes the oblique muscles went into contraction with the physiological leg flexors and adductors (flexors at the hip, adductors of the thigh, flexors at the knee, dorsiflexors at the ankle and the muscles which move the toes upwards).

Tone of the muscles of the abdomen and legs :—

(1) When *passive*: The tone, though below normal, of the flexors of the legs and recti abdominis was greater than that of the extensors of the legs and of the abdominal oblique muscles, but the difference in tone between the two muscle groups was, though considerable, less than it had ever been.

(2) When *contracting*: If the flexors of the limb or the abdominal recti were in spasm the tone of these muscles was greatly above normal, while the tone of the limb extensors was very much diminished. When the extensors of the limb were contracting the converse was true. But when a flexion reflex was induced by stimulating one sole and the crossed extensors contracted their tone was increased, but it never was so great as the tone of the contracting flexors. Often the contralateral extensors could only be felt to contract.

Wasting: Both the patient and I considered that the limb flexors had wasted little if at all. The extensors on the other hand were a little wasted.

Posture of the legs when not in spasm: They were slightly flexed and adducted at the hip, slightly flexed at the knee, dorsiflexed at the ankle, the toes were pointing a little upward. The great toe was extended at the interphalangeal joint and the small toes were a little plantar-flexed at these joints. The feet were slightly inverted.

Reflexes.—(1) Abdominals: (*a*) Rectus. Scratching the skin over one rectus produced contraction of that muscle and usually an ipsilateral flexion reflex in the leg. The response was only slightly delayed. If the stimulus was strong both recti contracted with flexion at all joints of both legs. The oblique muscles did not contract unless the pin was dragged on to the skin over them. A bilateral rectus response could be evoked by: (i) A strong nocuous stimulus (scratching) applied to the skin of the abdominal wall in or

near the middle-line from the pubis to the umbilicus. The response was often accompanied by a flexion reflex of both legs, though sometimes the extensor muscles of the legs could be seen to contract first. The extension phase when it was noticed was very short and was never complete. (ii) Squeezing the glans penis through the prepuce and especially when the organ was in erection. (*b*) Obliques. On dragging a pin over the skin covering the external oblique of one side a local contraction occurred which followed the anatomical direction of the fibres of the muscle—i.e., outwards and upwards when the pin was dragged from the rectus sheath outwards. The response was more delayed than was the rectus response and it was never crossed. No leg movements accompanied it and the rectus did not contract unless the stimulus was strong (e.g., a pin dragged heavily over the skin for a short distance). It was most easily evoked from the lower abdominal segment.

(2) Cremasterics were easily elicited on both sides.

(3) Bulbo-cavernosus reflex was active and was evoked by pricking either half of the glans penis.

(4) A composite reflex which resulted from stimulation of the penis if the prepuce was pulled forwards over the glans or the glans was gently squeezed through the prepuce. This was the most effective stimulus, but the reflex could be evoked by scratching the skin round the external genitals. The reflexogenous area extended from the genitals on to the skin of the abdominal wall for a short distance above the pubis, to the skin of the perineum between the thighs and to the skin of the inner surfaces of the thighs for a short distance. The threshold was lowest on the glans penis. The threshold increased with the distance from the genitals, and on the skin of the abdomen, perineum and thighs the adequate stimulus was a scratch. On an adequate stimulus the penis erected, the testes were drawn up, and the dartos muscle slowly contracted; then the bulbo-cavernosus muscle and the abdominal recti contracted sharply, and the legs became flexed and adducted at the hip, flexed at the knee, dorsiflexed at the ankles, and the toes bent upward. The response lasted as long as the stimulus was applied, provided it was not of long duration. It was little if at all delayed. Though a complete bilateral flexion reflex seemed to be the response in the legs, if they were closely watched it could be seen that the flexion was preceded by a quick, short contraction of the extensors of the knee and of the calf muscles; but the contraction was so brief that it was apt to be overlooked. If the stimulus was applied several times in succession sweating of the palms of the hands and of the skin of the trunk below the fourth rib and of the legs formed part of the general response. Should the reflex be evoked by scratching the skin of one thigh then the motor response was stronger on that side.

(5) On pricking the skin over the buttocks the anal sphincter contracted. The threshold was lowest near the anus.

(6) Flexion reflex. It was very easily obtained on both legs. The reflexogenous area extended from either sole on to the abdominal wall. The threshold was lowest in the sole and increased with the distance from the sole. With a

flexion reflex of one leg sometimes contraction of the crossed extensors occurred, sometimes crossed flexion preceded by brief contraction of the extensors. The ipsilateral rectus abdominis was frequently involved in the reflex especially if the stimulus was strong. When crossed flexion was evoked usually both abdominal recti contracted. Sweating of the skin of the palms, of the trunk below the fourth rib and of the legs was provoked by inducing several vigorous flexion reflex responses in the legs. The skin of the rest of the body remained dry. The bladder when it contained an adequate amount of urine could be made to "fire off" with a flexion reflex response.

(7) On pressing the foot sharply upwards sometimes a brief clonus occurred. Active extension of the lower limb could not be evoked by a similar stimulus when the limb had been passively flexed previous to its application. The movement was followed by a vigorous flexion reflex. More often, however, a clonus of the calf muscles could not be made out, and the stimulus gave rise simply to a flexion reflex of that leg to its application, which was followed by similar response in the other. Knee-jerks and ankle-jerks greatly exaggerated right and left.

Sensation.—For the previous two months he had periodic attacks of mastitis in the left mammary gland. The gland was tender to touch. During an attack areas of hyperalgesia could be made out along the left fifth dorsal sensory segmental distribution. A distinct swelling under the nipple could be felt. He had no sensations which could be referred to the abdomen, and he could not feel deep pressure applied by hand below the epigastrium. During the attack of pyelitis in February he had vague, uncomfortable feelings in the abdomen which he could not localize. Sometimes he thought they were in the region of the umbilicus. Total loss of sensibility below the sixth rib in front.

Vasomotor and trophic changes.—(1) Sweating. (*a*) Area of sweating: The skin of the trunk and legs below the fourth rib and the palms of the hands, were usually moist, and sometimes the dorsal surface of the fingers. The arms have never been noticed to sweat. The sweating was more profuse from the back when he was sitting against pillows, from the soles of the feet when they were pressed against pillows, and from the lower part of the chest and upper part of the abdomen when the arms were folded across these parts and resting on them. (*b*) Adequate stimuli for bringing on sweating and for increasing the amount of the sweating: (1) Spasms of the legs: repeatedly induced flexion reflexes were accompanied by increased sweating of the skin of the sweating area. (2) An enema administered when he was lying on his side. (3) Catheterization. (4) Change of temperature. When he was lifted out of his bath the sweat poured from the palms, from the lower half of the chest and from the abdomen and legs. He began to sweat profusely, too, shortly after he was put back to bed. As a rule he sweated less when he was up and sitting in a chair than when he was in bed. The sweating was as profuse as it had ever been and the sweating area had not changed. The head, neck, shoulders, arms, except the hands, and the upper part of the chest

were always perfectly dry. Sweating occurred from these parts only when his temperature was raised or when he was given aspirin, and then it was never so profuse as it was from the usual skin area. No change in the pulse or in the pupils had ever been noticed to accompany the sweating.

(2) Bed-sore: Some bone could still be felt at the base of the sore, but there was practically no slough left. It was very much cleaner and was healing from the edges.

Sphincters.—The bladder was as usual acting reflexly. Catheter was being passed twice daily, and the bladder was washed out every evening. The following observations were made: Catheter was passed and 420 c.c. of urine were drawn off. On pressing deeply into the hypogastrium no more came away.

(1) Solution of eusol in water 1 in 16,000 was poured into the bladder through a glass funnel, the point of which was inserted into the catheter. The bladder "fired off" at 325 c.c.; 300 c.c. were evacuated. The glans penis was rubbed and 10 c.c. more were voided. An additional 10 c.c. came away when the hand was pressed on the abdomen in the hypogastric region.

(2) Fluid was poured in. Evacuation occurred at 195 c.c. (he had taken a long breath). Evacuated 190 c.c. By rubbing the glans penis, 5 c.c. By pressing in the hypogastric region, 5 c.c.

(3) Fluid poured in. Evacuation occurred at 295 c.c. Evacuated 300 c.c. By rubbing the glans penis, 5 c.c. Nothing was recovered by pressing in the hypogastric region.

It was obvious from these observations, on comparing them with those made on January 11, that the bladder capacity had diminished. This was in all probability due to the attack of cystitis and pyelitis from which he suffered in February. Nevertheless, very little residual urine was being left. As before, respiratory oscillations were seen in the column of fluid in the tube, which were quite distinct from the bigger oscillations that immediately preceded the backflow. When the backflow began the mouth of the tube was never allowed to fall below the level of the abdominal wall.

When the catheter was being passed along the urethra, as its point came against the sphincter, considerable resistance was offered to its passage. With a little manipulation and gentle and steady pressure the resistance diminished and the catheter entered the bladder. The sphincter then held it fairly tightly, as was evidenced by the force required to remove the catheter.

Like the bladder, the rectum evacuated automatically. Dribbling of fæces was never known to occur. When an enema was given the amount of fluid required to be passed into the rectum to start an evacuation depended on the amount of fæcal matter in the rectum. It varied from 2 oz. to 6 or 8 oz. When the necessary amount of fluid had been injected the sphincter relaxed and the fluid and fæces were voided all at once. Then the sphincter tightened on the enema tube again. Sometimes several small vacuations occurred, but there was not a constant dribble. The rectal wall contracted on its contents and expelled them.

On pricking the skin of the buttocks the sphincter ani contracted. The most vigorous contraction resulted from pricking near the anus.

Condition on April 29 (266 *Days after the Injury*).

Bladder.—The following observations were made on this date: When the penis was swabbed with antiseptic solution preparatory to passing the catheter 85 c.c. of urine were voided. With catheter 200 c.c. were drawn off. Glans penis rubbed, 0 c.c. Pressure applied by hand on hypogastrium, 0 c.c.

(1) Solution of eusol 1 in 16,000 was poured into the bladder through a funnel. Backflow began when 180 c.c. had been poured in. Evacuated 180 c.c. Glans penis rubbed, 0 c.c. Pressure applied by hand to hypogastrium, 0 c.c.

(2) Fluid poured in and evacuation began at 210 c.c. Evacuated 210 c.c. Glans penis rubbed, 0 c.c. Pressure applied to the hypogastrium, 0 c.c.

(3) Fluid poured in and evacuation began at 240 c.c. Evacuated 240 c.c. Glans penis rubbed, 0 c.c. Pressure applied to the hypogastrium, 0 c.c.

(4) 100 c.c. of fluid were poured in. A flexion reflex was induced by scratching the left sole. A few bubbles came up through the fluid in the tube and the column remained stationary for a few seconds, but no backflow occurred. Similar result when right sole was scratched. 10 c.c. of fluid were added. Strong flexion of the right leg was evoked by scratching the sole. The bladder evacuated 105 c.c.

115 c.c. were poured into the bladder and flexion of leg induced by scratching the sole. The column of fluid remained stationary for a short time, but the fluid was not voided. 10 c.c. were added and flexion reflex was again evoked. Backflow occurred and 130 c.c. were evacuated.

Sweating.—The skin of the body was examined before the above observations were made, and it was found to be perfectly dry. In three-quarters of an hour, when the observations were finished, the skin was again examined. The legs up to the thighs were pouring sweat, and the skin of the trunk below the fourth rib and of the palms was distinctly damp. The rest of the body was as dry as at the beginning. He declared that he could usually tell when sweating was about to begin by the onset of "drumming in the head or a feeling of fatheadedness."

Condition on May 23 (290 *Days after the Injury*).

The following note was made with Dr. Head:—

Motion.—As the patient lay in bed, the usual movement of the legs was a flexor spasm. Usually the right leg fell into spasm more often than did the left. When sitting up, a common spasm was extension at the knee with inward rotation of the leg. The action of the great toe was somewhat puzzling, for it first seemed to make an upward movement, followed by a downward movement, and then up again. The foot appeared to plantar extend.

Reflexes.—On scratching the sole of either foot, flexion occurred at knee and hip, the ankle dorsiflexed, and the toes went up. The flexor movement reached its height after the brief stimulus had been removed, and then the leg slowly

straightened. It was liable to end in extensor spasm. Flexion was maintained for several seconds at its height if the reflex was vigorous. The falling back was now intermittent, and the hamstring tendons could be felt to jerk.

There was frequently a crossed contraction of the hamstrings, which was, however, always slight. If the ipsilateral flexion reflex was weak, the crossed reflex frequently did not come off. Crossed extension was not obtained.

Abdominals: Nocuous stimulation of the skin gave a mass-reflex, consisting of contraction of the muscles of the ventral abdominal wall and a bilateral flexor spasm of the lower extremities. Sometimes movement of the toes was the only movement of the lower limbs.

Erection of the penis was easily obtained, and when the prepuce was drawn over the glans a bilateral spasm of the muscles of the abdominal wall, chiefly of the recti and of the flexors of the lower extremities, was evoked.

Condition on June 21 (319 Days after the Injury).

Sensations referred to the paralysed parts.—Most abdominal sensations were referred to the epigastric region. When he had any gastro-intestinal trouble, he got a burning feeling in the epigastric angle which he was unable to locate exactly. Between the umbilicus and pubis along an oblique line running outwards on either side from the linea alba, he had a feeling of light pressure, which was aggravated by taking a deep breath. When the abdominal muscles were in spasm, the feeling of pressure was referred to the whole abdominal surface, but chiefly to the epigastric region.

On June 18 (316 days after the injury) the following observations had been made. Swabbing the penis caused erection and no urine was voided; passage of the catheter drew off 410 c.c. On running fluid into the bladder he evacuated it at 490 c.c., passing the total amount: nothing could be recovered by pressure. Then 400 c.c. were passed into the bladder and the catheter carefully removed; on scratching the thigh he immediately returned 80 c.c. in a strong stream. From this time onwards he found that he could provoke involuntary micturition by scratching the groins or thighs.

Urine: Acid, a trace of albumin; no sugar; deposit of pus and bacilli; cultures, *B. proteus*.

Condition on June 27 (325 Days after the Injury).

Bladder observations with Dr. Head.

Catheter was passed, and 190 c.c. of urine were drawn off. Fluid was poured into the bladder through the burette in the usual way. Evacuated at 425 c.c. Evacuated 420 c.c. Nothing was recovered by pressure.

Fluid was again poured into the bladder. Evacuated at 420 c.c., and evacuated the whole amount. Nothing by pressure on the hypogastrium.

Fluid poured in. The patient was asked to breathe deeply during the entry of fluid. Evacuation occurred at 58 c.c., and 60 c.c. were passed. Nothing by pressure.

Patient again asked to breathe deeply while the fluid was being poured into the bladder. Evacuated at 25 c.c. and passed 30 c.c. Pressure *nil*.

With flexion reflexes evoked from right foot, after 50 c.c. had passed into the bladder, every reflex caused hesitation, but evacuation did not occur till 160 c.c. was the bladder content. The whole amount was voided. Pressure *nil*.

350 c.c. of fluid were inserted, and just as this amount was reached he evacuated and passed 350 c.c. Pressure *nil*.

200 c.c. were poured in. Catheter removed. The sole of the foot, and then the thigh, was scratched, but evacuation did not occur. Deep breathing was equally ineffective. Catheter was again passed, and he immediately "fired off," passing the whole 200 c.c.

Reflexes.—Knee-jerks and ankle-jerks exaggerated. No definite ankle clonus, but a few irregular jerks were obtained on the right side. One of the difficulties encountered in testing the clonus was the immediate flexor-adductor spasm evoked by touching the foot. Plantar reflex was "extensor" with profound flexor spasm. Flexor spasms could be evoked from any contact with the lower extremities. No general reflex was obtained from the abdomen. Distinct, though rather feeble, contraction was evoked across the stimulated area in the region of the umbilicus.

Sensation.—Exactly as before; upper level of loss sixth thoracic segment.

Motion.—Total voluntary paralysis below the sixth rib. Flexor-adductor spasms were frequent and strong.

Vasomotor and trophic changes.—The patient was not sweating so much as he used to do. He shivered more, but with no rise of temperature. The sweating occurred as usual from the nipples downwards and on the thighs and palms of the hands during the observations on the bladder. The actual secretion of sweat was less, but the shivering was more. It was particularly liable to come on at the end of the day. A bath, hot milk, or an enema always brought on the sweating. He said that when he had the feeling of drumming in the ears a hot sweat came on. When there was no drumming in the ears, and he sweated, he got a cold shivering feeling with the sweating. The bed-sore was extremely clean, and was covered for the greater part with a glazed surface, as if the epithelium was growing into the pit from the edges.

Sphincters.—Sphincter ani active and tonic. The rectum, like the bladder, was evacuating its contents reflexly.

Chapter III.—(*a*) The Course which the Cases run.

If uncomplicated from the first by any serious condition, such as a severe chest wound, sloughing bed-sores or urinary sepsis, the course follows a fairly definite plan. It may be useful here to summarize the clinical picture, using No. 1 of this series as a basis for description.

The instant No. 1 was shot he dropped to the ground. The sensations he experienced at that time are instructive, for he had no

pain to distract his attention. With dramatic suddenness his body seemed to be cut in two. He was alive with a body which consisted of a head, a neck, arms and the upper part of a chest. Legs and abdomen were non-existent to him. The shock had not affected the brain and proximal part of the spinal cord, for his mind was clear and he was unaware of any difficulty in breathing or of any abnormal action of the heart. It was only during the jolting journey to the dressing station that his consciousness became dulled.

When he came to be examined, all voluntary muscles below the fifth rib were found to be paralysed and toneless. The legs lay limp on the bed. No reflexes could be obtained from the abdominal wall and lower limbs. At times he had cramp-like pains round the chest at about the level of the fifth interspace. Below the sixth rib all sensibility was gone. The muscles of the bladder and rectal walls were paralysed, but from the beginning there was retention of urine and fæces. Sphincter tonus was the only apparent sign of life in the paralysed parts. The penis was flaccid and erection could not be induced. He had no seminal emissions. The legs were not swollen and the skin was dry. Abdominal distension caused some discomfort in breathing.

Such was the clinical picture for twenty-two days. Then a second stage was entered upon. Reflexes began to appear. A flexion reflex, at first modified in the extent of movement, though complete as regards the muscles involved, could be evoked in either leg by nocuous stimulation of the sole. In No. 3 downgoing movement and adduction of the toes was the earliest response to a scratch applied to the sole, and in others, at the time of their admission to the Empire Hospital, this toe movement accompanied contraction of the flexors of the hip and knee and the adductors of the thigh. Later the typical flexion reflex developed with upgoing and abducted toes. The bladder-wall, and at about the same time the rectal wall began to function, and urine was voided at irregular intervals. These signs of reflex activity in the isolated cord were followed by various other reflexes. Involuntary flexion movements of the lower extremities soon became vigorous. Tendon jerks, abdominal, cremasteric, and bulbo-cavernosus reflexes could be elicited by appropriate stimulation. Erection of the penis was frequent and semen was emitted. There was little muscular wasting and what there was was evident in the limb extensors only—namely, the quadriceps cruris and calf muscles. The reflex functions of the bladder recovered more and more till ultimately it expelled nearly all its contents. The bowel became almost independent of help. A striking

feature was the complete absence of visceral sensibility in the abdomen below the epigastrium. At first the skin of the paralysed parts was dry, but in time the patient began to sweat from the nipples down and from the palms of the hands. Bed-sores healed well with suitable attention.

This stage of reflex activity may go on for months or, so far as I know, indefinitely, but as a rule intercurrent affections modify it or bring it to a close. Should toxic absorption begin early, as from a severe septic wound or from a sloughing bed-sore, or acute cystitis, while the spinal cord is still under the influence of "shock," its functional activity may recover to a very indifferent degree. The clinical picture, as in No. 5, will then closely resemble that described by Bastian as being characteristic of complete transection of the cord. The limbs are flabby and almost devoid of tone, they waste rapidly and the only sign of reflex activity evident in them is a feeble flexion reflex following intense nocuous stimulation of the sole. Involuntary spasms are absent and knee- and ankle-jerks cannot be obtained. Automatic evacuation of the bladder and rectum never appears, or at best very imperfectly.

More frequently the picture is blurred later when reflexes have appeared and are in full swing. Urinary infection, so common a complication of spinal injuries, may not give rise to general symptoms of toxæmia for weeks after the illness has begun; but one attack too often leads to another, to kidney involvement and to death. During an attack of pyelitis, in the stage of reflex activity, the involuntary flexor spasms of the lower limbs and abdominal wall diminish in frequency and in vigour. The paralysed muscles tend to waste and to lose tone, the extensors more than the flexors. The threshold value of stimuli increases and receptive fields for reflexes become smaller. Reflexes that have newly appeared cannot be evoked, and whereas previously a strong nociceptive stimulus applied to the sole set up a response over a wide muscular field, the reflex effect becomes simpler. With the rise of temperature, hyperidrosis becomes general, though more profuse over the usual sweating area. The vitality of the tissues is lowered and bed-sores appear or increase in size. The bladder expels less urine with each contraction and in consequence the residuum is greater. Even retention may return. The bowel is more sluggish and constipation is the rule. Later diarrhœa and vomiting appear as signs of the severity of the toxæmia.

If the attack is not severe, reflex activity returns as the general symptoms subside, and soon the legs fall into spasm as vigorously as

ever. But each attack leaves its mark on the nervous apparatus and muscles, and finally the last stage is reached which is clinically an accentuation of the first. All signs of reflex action ceases, tone in the sphincters disappearing last. Wasting becomes extreme, till ultimately the bones are covered with little more than unhealthy skin which sloughs with the slightest pressure and the patient dies.

(*b*) Analysis of the Stages.

(1) *Stage of Flaccidity.*

This stage corresponds roughly, in uncomplicated cases, to the period of suppression of reflex activity by "spinal shock," and it varied in three cases from one week to three weeks. Clinically it begins with the infliction of the injury to the cord and ends with the appearance of the first reflex response to an external stimulus applied to the abdominal wall or legs.

All voluntary muscles controlled by the cord below the level of section are paralysed, quiescent and atonic; but myotatic irritability, though diminished, is never absent. The lower limbs lie on the bed extended at hip and knee, usually rotated outward, a little plantar extended and inverted at the ankle, and the toes are either in line with the foot or flexed a little towards the sole. The muscles do not waste appreciably.

All cutaneous and tendon reflexes are absent except for reflex contraction of the external sphincter ani on pricking the skin of the perineum or buttocks near the anus, of the external sphincter of the bladder and of the cremaster and bulbo-cavernosus muscles when the glans penis is pinched or pricked. The penis is flaccid and semen is not voided.

An irregular zone of cutaneous hyperalgesia is usually present just above the insentient skin. It may correspond in breadth to one or two root areas, but as a rule it is patchy. The pain is typical of root irritation and is described as "needly" in character or as if it came from red and inflamed skin. The disagreeable sensitiveness of the skin is often accompanied by a feeling of superficial tightness as if an elastic band was fitted closely round the chest or abdomen at that level.

If the lesion of the cord is above the sixth thoracic segment, as in Nos. 2 and 3, abdominal visceral sensations may be entirely absent even when the bowel is distended with gas or is being firmly palpated by hand. A griping purge has no terrors for the patient. The bladder

may contain 30 or 40 oz. (850 to 1,140 c.c.) of urine without any other complaint from the patient than that his breathing is hampered. Nothing is felt when a catheter is passed nor when an enema is given. He is usually totally unaware from his sensations that he possesses an abdomen.

When the level of the transection is between the sixth and eighth thoracic segments, all abdominal sensations are referred to the epigastrium. The patient feels uncomfortable in that region only when the bowel or bladder is distended, and he sometimes complains of colic in the stomach.

In four of the cases the skin was dry during this stage. No. 5 on admission to the Empire Hospital was running a high temperature and the whole skin sweated moderately and equally. Erythema is readily produced by pressure or by scratching. I have not seen urticaria in these cases. Œdema of one or of both lower extremities is a common feature of this stage of muscular flaccidity, and is due probably in most instances not to venous thrombosis but to pressure exerted on the unsupported femoral veins by a tilted pelvis. The limbs swell quickly if they are allowed to hang down and special care has to be taken to prevent the development of bed-sores. The skin and deep tissues are much more liable to slough or become septic and sores are more difficult to heal when the isolated cord segments are under the influence of "shock" than during the second stage of reflex activity. Distension of the bowel is always a prominent symptom and it lasts generally for the whole of this stage. The paralysed parts lose heat rapidly and are always colder than normal.

There is retention of urine and fæces due to tonic contraction of the sphincters. For some time before automatic micturition begins, while clinically there is still retention, the detrusor of the bladder can be demonstrated to contract against an appropriate and fairly constant fluid content. Thus, during the ordinary bladder lavage of a case not included in this series, fluid was poured into the bladder through a catheter at as small a head of pressure as possible. When the bladder contained 80 to 90 c.c. the detrusor vesicæ contracted and expelled practically the whole amount. The stream was feeble and could be easily arrested by raising the burette a few inches, showing that detrusor action was weak and in consequence unable to overcome the tonic contraction of the sphincter. But when the sphincter had been opened by the catheter it was sufficiently strong to expel the contained fluid provided the pressure was not great. Soon after this condition was determined automatic micturition began.

(2) *Stage of Reflex Activity.*

This stage is entered upon when in response to stimulation of the skin or deep structures a reflex contraction of the muscles of the lower extremities or abdominal wall can be evoked. In Nos. 1, 2, 4 and 5, the first reflex to be elicited was a reduced flexion reflex on nocuous stimulation (scratching) of the sole. In No. 3 contraction of the rectus abdominis on scratching the overlying skin was the earliest reflex to be evoked. It is noteworthy that the first muscle-groups to respond to a stimulus were flexors, whose function it is to shorten the limb or trunk, and that the only adequate stimulus was nociceptive.

In animals, as Sherrington has pointed out, a similar reflex response is the earliest to appear after severance of the spinal cord and that throughout the stage of reflex activity it is prepotent. Walshe believes that after complete spinal transection in man, a minimal flexion reflex is the only sign of reflex activity that persists in the lower extremities. As will be evident later, the flexor or phasic muscles not only show reflex activities first but they remain most active throughout.

Motion.—As a rule the earliest involuntary movements to be observed are in the legs and they are flexor in character. The muscles involved are the flexors of the hip, adductors of the thigh, flexors of the knee, dorsiflexors of the ankle and usually the muscles which pull up and abduct the toes. At first the only joints at which actual movement can be observed are the metatarso-phalangeal and interphalangeal of the toes and perhaps more at those of the great toe than of the others. But by palpating the anterior tibial tendon and the tendons of the inner hamstrings and adductors of the thigh one is satisfied that the contraction of these muscles is simultaneous with the toe movements, though it is not of sufficient strength at first to move the limb at hip, knee and ankle. It is likely that in even the early involuntary movements of the limbs every muscle whose action is to shorten the limb contracts. The toes move alone not because their flexors react more vigorously than do the flexors of the hip, knee and ankle, but because their mechanical load is less.

Upgoing toe movements do not, however, invariably accompany early flexor spasms of the legs. In No. 3 downgoing movement of the toes accompanied contraction of the limb flexors for some time, but later, as the spasms increased in vigour, the direction of movement gradually became upwards. With heightened reflex activity of the limbs, the spasms become stronger and more frequent. The ipsilateral

rectus abdominis, if the lesion is high enough, is soon involved in the spasm, so that the patient with each jerk is pulled forward and to the reacting side. Sometimes the spasm begins in the abdominal rectus and spreads to the limb. A spasm at the active stage is a quick flexion which is maintained for a few seconds and is followed by passive extension of the leg. The after-extension is apparently due to gravity and to relaxation of the flexors and not to contraction of the extensor muscles.

Most often the lower extremities are thrown into spasm irregularly and unequally, one giving two or more short jerks before the other moves. Sometimes the movements are confined to one lower limb for hours at a time and it may be consistently more active than the other throughout. Occasionally, as in No. 1, the limbs fall into spasm alternately more or less regularly for short intervals. The movement may be bilateral, and then as a rule it originates in the abdominal recti and spreads to the lower extremities.

For some time after involuntary movements have appeared, the extensor muscles remain flabby and do not participate in the spasms. Later, as they recover some of their tone, with flexion of one limb contraction of the quadriceps of the other may be felt, but, in my experience, crossed extension is rare, and is feeble. Contraction of the flexors is invariably accompanied by inhibition of tone in the extensors of the same lower limb.

The abdominal oblique muscles are involved in the most severe spasms only of the abdominal recti and of the limb flexors, and, when in contraction, they offer less resistance to pressure with the hand than do the recti. Their tone is less. Steppage movements of the feet and legs, such as are seen in many cases of partial injury of the cord and in spinal animals, in which there is flexion of one lower limb with extension of the other, then vice versa and so on, were never observed. Throughout, the extensor system of musculature—i.e., those muscle-groups of the legs and trunk which subserve the upright posture—is reflexly much less excitable than is the flexor system of muscles which shorten the trunk and lower limbs.

Muscular tone.—Muscular tonus returns with reflex activity in the muscles of the abdomen and legs. With the appearance of involuntary flexor movements and the induced flexion reflex, the flexors begin to lose their flabby and shapeless look. They become more naturally rounded, their curves return, they are less putty-like, and offer a fair degree of resistance to the finger. The quadriceps cruris and calf

muscles of the lower extremities and oblique muscles of the abdomen, which are at this stage reflexly inactive, remain atonic and flabby. Some degree of firmness is evident in them only when their reflex arcs show signs of life. The knee-jerks were obtained on an average seventeen days after the appearance of the flexion reflex. The tone of the quadriceps cruris and calf muscles increases as the limbs become reflexly more active, but it never approximates to that of the hamstrings and pretibial muscles and of the recti abdominis. The relative degree of tonus exhibited by the two functionally antagonistic muscle groups corresponds with their relative degree of reflex activity. The difference in the tonus of extensor and flexor muscles is probably most marked when the muscles are resting. This is a very noticeable feature in the clinical course, but in No. 1 in the later stages of heightened reflex activity the difference in the tonus of the two muscle-groups, though still evident, became less marked. The tone of all the paralysed muscles in the resting state never reaches that of the muscles of a normal individual. They are more or less hypotonic.

Muscular wasting.—Provided intercurrent disease does not blur the "spinal picture," muscular wasting is almost entirely absent. Any loss of substance that may have been evident in the first stage of flaccidity quickly reappears as the flexor spasms become vigorous. It is only in those muscles, the extensors, which are relatively less reflexly active, that any sign of wasting remains. The limbs, rounded, firm and well nourished, are at a casual glance indistinguishable from those of a normal person. Even after a short-lived attack of pyelitis, lasting for ten days or a fortnight, during which the muscles have suffered a little, the legs soon recover their original size provided the reflex arcs are in high functional activity.

Number of case	Level of lesion	Flexion reflex (hamstring contraction) palpable	Knee-jerk	Abdominals (recti)	Erection of penis	Automatic bladder
1	Sixth thoracic	22	25 (R.), 31 (L.)	34	?	22
3	Third thoracic	10	21	7	19	29
4	Ninth thoracic	6	42	Not obtained	27	28

TABLE to show the approximate number of days, after the injury, that elapsed before some of the reflexes were obtained in three of the cases.

Reflexes.—Flexion Reflex.

In at least four cases of this series the stage of reflex activity was opened with the appearance of this reflex. The average time after the injury that elapsed before it could be evoked in three patients was thirteen days. In No. 4 it was present on the sixth day.

(*a*) *Adequate stimuli.*—The stimulus adequate to elicit this reflex is of nociceptive character, and it may be applied either to the skin or to the deep structures of the lower extremity. A scratch or prick with a pin may be taken to be stimuli of moderate intensity, while pinching or squeezing has a greater degree of harmfulness. The faradic current can be graded and is an admirable experimental stimulus. At first, when the reflex is feeble, the stimulus necessary to evoke a motor response has to be strong, but later, as reflex excitability increases, its threshold value becomes lowered, especially in the sole, the central focal area of the reflex. Then a stimulus of less intense nature, such as tickling, will elicit a complete flexion reflex, though one of less vigour than that produced by a prick or scratch. A stimulus, in itself subliminal, will, if repeated, effect a motor reply in every way complete. The sum of weak stimuli in its end-result is the same as a single strong stimulus.

The interval between the application of the stimulus and the appearance of the muscular contraction is longer with weak than with intense stimulation, and it varies also with the functional activity of the reflex centres. In No. 1 an interval of several seconds elapsed before hamstring contraction could be felt in response to a scratch of moderate strength applied to the sole in the days succeeding the emergence of the reflex from "shock," but later the reaction time diminished so much that to the eye a definite interval could hardly be noticed.

(*b*) *Receptive field for the reflex.*—At first the reflex can be excited only from the planta, but with heightened reflex activity the reflexogenous area rapidly extends up the leg, and soon, in all uncomplicated cases, reaches the groin and perineum. But throughout the sole remains the central focal area in the field for the reflex and the threshold value of the stimulus gradually increases towards the base of the limb. As a rule the inner aspect of the thigh is more receptive than the outer aspect, and the outer more than the inner surface of the leg, but there is considerable variability even from day to day, and more so in different cases in the ease with which the reflex can be evoked from different parts of the field. Excitation not only of the

receptors of the skin but also of the deep structures of the limb is capable of eliciting the reflex. To whichever part of the lower extremity a stimulus of adequate pathic quality is applied, when reflex activity has become fully established, the motor response is invariably a flexion reflex of the limb true to type.

(*c*) *Motor reflex response.*—The earliest reflex obtained by nocuous stimulation of the sole varies, in my experience, in different cases. Probably the most important factor to which this can be attributed is the difference in time after the injury at which the cases were first examined. Some arrived in hospital in London a few days after they were wounded, while the functions of the spinal cord were still suppressed from "shock." In these the whole progress of events could be systematically studied. But other patients spent the earlier weeks of their illness in France, and by the time they were transferred to England they showed considerable recovery of reflex excitability in the paralysed parts. We have, however, the advantage of the observations of Gordon Holmes on the early manifestations of reflex activity in the lower limbs. The flexion-adduction movement of the toes which he and Collier describe as occurring in certain cases, believed to be of partial though severe damage to the cord, was the response I obtained in two of the cases of complete cord transection admitted earliest to the Empire Hospital. It consisted of contraction of the short "flexors" and adductors of the toes, the movement being chiefly at the metatarso-phalangeal joints, in response to scratching of the sole only; it was not accompanied by palpable tightening of the tendons of the inner hamstrings or of any other muscles of the lower limb. In No. 3 it was obtained on the seventh day, and in another patient on the eighth day after the injury. Holmes has described it as a "unisegmental reflex response" in muscles supplied by the first sacral segment, which also receives the impulses originated by the stimulus applied to the sole. This is probably the most common early reflex manifestation in the lower limbs when the cord is completely divided.

A little later (three days in No. 3 and 15 days in another patient) the downgoing toe movement was accompanied by contraction of the inner hamstrings. In Nos. 4 and 5 this was the response evoked on the date of their admission to hospital, on the sixth and sixteenth days respectively following the injury. Walshe [42] has observed a similar reflex in cases of paraplegia from spinal disease, and explains the part played by the toes as being due to passive pull exerted on the deep structures of the sole, including the plantar flexors of the toes when the

foot is dorsiflexed in the reflex movement of the limb. This may be so in those rare cases in which vigorous action of the pretibial muscles precedes definite toe movement, but it does not explain the response when no movement at the ankle takes place at all. The question will be considered later in another chapter. Contracture of the small muscles of the sole when present would, of course, preclude any other movement, even if the flexors of the leg were responding vigorously.

Downward movement of the toes does not, however, persist for any length of time as the toe-phenomenon of the flexion reflex of the lower limb. As the patency of the reflex arcs increases, the toes gradually move in the opposite direction till ultimately (in No. 4, forty-two days, and in No. 3, twenty-nine days after the injury) they definitely move up and "fan." During the transition stage, the toe response may depend on the intensity of the stimulus exciting it. Thus, on the fourteenth day after No. 4 was wounded, a scratch of moderate intensity applied to the left sole evoked contraction of the inner hamstrings and downgoing toes. With a stronger stimulus, there was flexion at the knee and ankle and brief downward movement of the toes, followed by an upward movement. The response in the right leg was similar to that obtained in the left, except that occasionally upward movement of the toes occurred without an initial downward movement.

Upgoing toes with hamstring contraction was evoked in No. 1 on the twenty-second day, as the first reflex response in the lower limbs. It remained true to type throughout the ten months he was under observation.

The response for some time may differ in the two sides in the same patient. The left leg in No. 2 gave a definite upward movement of all toes, while in the right there was very little toe movement. In both, contraction of tensor fasciæ femoris, hamstrings and dorsiflexors of the ankles was obtained. In No. 4, too, as mentioned above, the reflexes differed a little in the two lower limbs.

Soon, whatever the character of the early toe response may be, the motor-reply to nocuous stimulation of the sole is contraction of the flexors of the hip and knee, of the adductors of the thigh, the dorsiflexors of the foot and toes and the abductors of the toes. At first the only joints at which actual movements can be seen in the flexion reflex of the leg are the metatarso-phalangeal, and perhaps, though more doubtfully, the interphalangeal of the toes. The con-

traction of the other flexors of the lower limb, though palpable, is not at this early stage sufficient to move the limb at the hip, knee or ankle; tightening of the inner hamstring tendons is always more evident than of the others. But as the facility of the reflex develops so the muscular response becomes more and more vigorous, and the limb flexes briskly at all joints. The movements of the stimulated leg, in a complete and active flexion reflex, consist of flexion at the hip with adduction of the thigh, flexion at the knee, dorsiflexion at the ankle, and upward movement and fanning of the toes. The muscles which can be seen or felt to contract are: Ilio-psoas, tensor fasciæ femoris, rectus femoris, gracilis, adductors of the thigh, semitendinosus, long head of biceps, pretibial and peroneal muscles.

The movement resembles in every way an involuntary flexor spasm, the flexion or first phase of the reflex-effect being a quick bending of the leg, not sustained for long, followed by a quick non-tremulous falling away to the original extended position. It might be compared to a low tension pulse with its steep ascent, short maintenance, and its slightly less steep descent. When the exciting stimulus is continued the spasm is sustained for a somewhat longer time, but it is tremulous and soon falls away. The response to a single brief stimulus outlasts the application of the stimulus and the height of the spasm arrives after the stimulus has been removed, but it is never maintained by continuous stimulation.

The reaction time for the reflex is longest when it first emerges from "shock," and gradually diminishes with the greater responsiveness of the arcs to excitation, but throughout it is appreciable to the eye. The gradual diminution of the latent period could be well studied in No. 4. The complete reflex can be evoked from any part of the receptive field. Individual reflexes as elicited by stimulation of widely separated points in the field do sometimes differ slightly, but they all conform to the "typical" flexion reflex. The differences, which are variable, consist in the reflex contraction excited by stimulation at one point involving certain flexor muscles less than it does when excited from another point in the receptive field. Thus, when the anterior or upper aspect of the thigh is scratched, the contraction of the adductors and of the flexors of the hip, including the rectus femoris, is relatively vigorous and the upward toe movement is relatively less than when the sole is the part stimulated. The difference is sometimes noticeable when reflexes are elicited from two not very distant parts of the skin. In Nos. 1, 3 and 4, with the flexion reflex evoked by scratching the

outer part of the sole, the foot tended to evert, while with that obtained from the inner border of the sole the tendency of the foot was more to invert.

With contraction of the limb flexors—i.e., in the first phase of the reflex—the condition of the extensors, their antagonists, alters. The reflex in them produces not contraction, but relaxation. Their tone is inhibited. This can be ascertained either by palpating such muscles as the vasti cruris, soleus and gastrocnemius, or by attempting to elicit a knee-jerk whilst a flexion reflex is in progress. In Sherrington's words [34] "reciprocal innervation of antagonistic muscles is a principle observed in the nervous taxis of the reflex. The reflex application of the principle seems, especially to muscular antagonism, such that were both muscles (flexor and extensor) to contract at the same time the main action of one muscle would impede the main action of the other."

In the second phase of the reflex, i.e., the straightening of the limb which follows the flexion, the flexors relax but the extensors (vasti cruris and calf muscles), though recovering their original slight tone, do not palpably contract; the falling away of the limb appears to be passive and due to gravity and to relaxation of the flexors. In certain cases of incomplete cord lesion, as will be described later, and in the spinal dog or cat, the extensors of the limb take an active part in the second phase of the reflex; in fact, after a vigorous flexor spasm their tone may be considerably heightened during that phase due to "post-inhibitory exaltation" described by Sherrington. The active contraction of the extensors in these cases in turn excites the flexor arcs, and alternate flexion and extension movements of the limb, resembling the motion of the limb in "marking time," may go on for a short period. These regular alternate movements of the limb have not been observed to follow an induced flexion reflex of the lower limb in spinal man; the reason for this may be that the reflex arcs which subserve extensor activity are relatively much more depressed by separation of the cord segments from headward centres than are the flexor reflex arcs.

Reflexes accessory to the Flexion Reflex.

(1) *Extension and flexion reflex in the crossed limb.*—In my series of eight cases of complete transection of the cord, contraction of the extensor muscles of the crossed limb was noted in two as an accompaniment of the induced flexion reflex. It would appear to be of rare occurrence, and in No. 1 it was confined to the vasti and was never

sufficiently strong to be much more than palpable and to cause a definite lengthening thrust of the leg. Even when eight months after the injury the reflex activity of the extensors was great and occasional extensor spasms occurred, the contraction of the vasti of the opposite limb could only be felt. The crossed extension reflex was usually of very brief duration and was often followed by crossed flexion. In No. 2, at one time crossed extension accompanied a flexion reflex and at another crossed flexion.

By far the most common crossed response was flexion, most at hip and knee, associated with adduction of the thigh. When the upper part of the thigh or the perineum were the parts excited, the limbs flexed almost simultaneously and symmetrically, but when the stimulus was applied to the leg or the foot the flexion reflex of the contralateral limb occurred a little later than the homolateral flexor spasm. The difference in reaction time appeared to diminish the nearer the locus of the stimulus approached to the perineum.

(2) *Reflex spread to muscles of the abdominal wall.*—A frequent accompaniment of a strong flexion reflex was contraction of the ipsilateral rectus abdominis. In No. 1 this accessory reflex response was evident about the same time (thirty-one days after the injury) as contraction of the crossed extensors. As the effects of spinal shock disappeared and activity of the reflex arcs increased, the "spread" could be provoked by less nocuous stimuli applied to the sole or to the greater part of the receptive field. It was most easily provoked from the sole and the anterior and inner aspects of the thigh near the groin. Though the abdominal response is, as a rule, limited to the rectus of the side of the flexing limb, with a strong reflex the irradiation may be wider. The following motor response may then be obtained from stimulation of the sole:—

(i) A vigorous flexion reflex of the stimulated limb.

(ii) Contralateral flexion or brief extension followed by flexion.

(iii) Contraction of the ipsilateral oblique and rectus muscles of the abdomen quickly spreading to the muscles of the other side.

The contraction may be so strong and sudden that the patient is shot downwards in the bed. The minimal motor response in the abdominal wall with a flexion reflex of the limb is ipsilateral rectus contraction.

(3) *Reflex evacuation of urine.*—In this stage of heightened reflex activity of the isolated cord, when the bladder is automatic, urine may be expelled from the bladder as part of a "massive" response induced

by scratching one sole. The necessary condition for this to happen is that the bladder should contain about one-third to one-half the amount of urine at which it usually evacuates its contents automatically.

(4) *Sweating.*—Sweating from certain regions of the skin often accompanied a vigorous flexion reflex. It was confined strictly in each case to certain specific skin areas, to be described later, and was obtained only when the reflex centres in the cord were very excitable.

Knee-jerk, Ankle-jerk, and Ankle Clonus.

The earliest date of appearance of extensor jerks was the twenty-first day, and the latest the fifty-third day after the injury. In one patient (No. 5) they were not obtained, but the patient died on the nineteenth day from severe complications which were present from the first. The table on p. 304 shows the dates on which the tendon-jerks were first noticed in three of the cases, and they can be compared with the corresponding approximate dates of return of some of the other reflexes. In Nos. 2, 3, and 4 the knee- and ankle-jerks returned together, while in No. 1 the knee-jerks appeared nine days in one leg and twenty days in the other before the ankle-jerks. A feeble and irregular ankle clonus was obtained in only two cases and appeared at a later date than either the knee- or ankle-jerks. Four or five irregular clonic jerks of the calf muscles could be obtained in No. 1 in the right leg fifty-seven days after the injury, and thirty-two days after the appearance of the right knee-jerk and twenty-three days later than the right ankle-jerk. In the left leg of the same patient ankle clonus (six or eight jerks) was evident on the ninetieth day, while the ankle-jerk had been evoked on the forty-fifth day after the date of the wound. More sustained calf clonus was elicited not earlier than the 259th day after the injury.

When a comparison is made between the relative reflex activities of the physiological flexor and extensor muscle-groups of the legs certain striking facts are brought to light. These will be discussed more fully in the next chapter.

(1) In the first place the flexion reflex was obtained from eleven to thirty-six days before the extensor reflex arcs showed any sign of recovery, taking the knee-jerk as evidence.

(2) Ankle clonus was elicited in two only of the cases. It was limited to three to eight jerks of unequal amplitude for many months. It became in one case only a more definite, though by no means a constant clonus, fully eight months after the infliction of the injury. During this time the flexion reflex had been extremely facile in both

legs and could be induced by appropriate stimulation of any part of the limb and from the abdominal wall.

(3) Contraction of the crossed extensors following on a flexion reflex appeared on the same date as the knee-jerk in No. 1; for many months it was only palpable. A crossed extension reflex was noted once in No. 2, and later crossed flexion was obtained. By far the most frequent crossed response was flexion.

(4) Ankle-jerks were not elicited in all the patients in whom the flexor arcs were highly excitable, and when present they tended at first, like the knee-jerks, to disappear on one day and reappear on another. The flexion reflex can always be obtained after it has once appeared, provided toxic febrile states do not complicate the case in the early stages of reflex recovery.

Reflex activity in the extensor muscle-groups is thus considerably less than in the flexor muscle-groups, and it shows great variability in different cases and at different times in the same case.

The reappearance of the extensor tendon-jerks is dependent on the return of tonus in the vasti cruris and calf muscles. During the period of "shock" the muscles are flabby and toneless and all signs of reflex activity in them are absent. Gradually they acquire more shape, they become less pliable and doughy to the touch, and on sharply tapping the patellar or Achillis tendons the muscles can be felt to contract and the slack tendon to tighten. That is the earliest apparent response, and for some time, even when muscular contraction can be seen, it expends itself in taking up slack in the muscle and no active movement occurs at the knee-joint. As recovery goes on, the lengthened hypotonic muscle gathers itself up more and more till the response to adequate stimulation is extension of the leg at the knee, and it justifies the name of knee-jerk. This occurred in No. 1, thirty-two days, and in No. 3, nine days after the first response in the vasti was evoked. With recovery of tone in the extensors the tendon-jerks become more brisk and vigorous till ultimately they are considerably above normal. I found that, as a rule, the calf muscles were relatively less active than were the extensors of the knee.

A very important feature of the extensor tendon-jerks in spinal man is the quick falling away of the contraction. The quadriceps muscle responds briskly to the sharp tap on its tendon, but it immediately relaxes again, the leg dropping like a dead weight. There is no tonic prolongation of the contraction such as occurs as a second phase in the intact individual, and in certain cases of incomplete cord lesion, when

the heightened tone in the muscle induced by the reflex gradually diminishes and the leg drops more gently. It is a very striking phenomenon, and one which has to be seen to be realized.

The knee- and ankle-jerks can be readily inhibited by provoking a flexion reflex of the ipsilateral limb, and they can sometimes be reinforced by scratching very gently the skin of the opposite lower limb so as to evoke a minimal flexion reflex. Intense excitation of the crossed limb may be followed by a flexion reflex as a crossed response in the lower extremity and then the knee-jerk is inhibited.

Nos. 1, 2, 3 and 4 showed a difference in the reflex excitability of the two lower extremities in both flexor and extensor muscle-groups. In No. 1 the right leg was the more active, and it remained so during the ten months he was under observation. As regards the extensor reflex arcs, the knee-jerk in the right leg returned on the twenty-fifth day and the ankle-jerk on the thirty-fourth day; and in the left the knee-jerk on the thirty-first day and the ankle-jerk on the forty-fifth day.

Sherrington ([33] p. 248) not uncommonly found differences in the reflex condition of the right and left limbs in animals (especially in the spinal monkey), even though the spinal transection gave a perfectly symmetrical spinal lesion. "Such inequality or dissimilarity of the spinal reflexes, right and left, does not necessarily afford any evidence that the spinal lesion is asymmetrical. Intercurrent circumstances suffice to impress slightly different reflex habits on the two limbs, and in one and the same individual the reflex habits of each limb may vary somewhat from period to period."

Abdominal reflexes.—Reflexes of great interest are those which can be evoked by stimulation of the abdominal wall. Physiologically the muscles of the abdominal wall can be classed under two heads:—

(1) The recti, which are flexors and belong to the kinetic or phasic group of muscles.

(2) The oblique and transversalis muscles, whose action seems to be chiefly postural, belong to the static muscular group.

The direction of the fibres of the recti is parallel to the axis of the body, while the fibres of the second group lie more or less transversely. The nature of their respective activities justifies this grouping.

The recovery of abdominal reflexes, as originated from stimulation of the skin of the wall, depends largely on the level at which the spinal cord is injured. In Nos. 1 and 3, in whom the last normal segments were respectively the fifth and fourth thoracic, they could be evoked early

and with great ease. They were easily obtained on the seventh day in No. 3 and were noticed first in No. 1, in the lower segments on the thirty-fourth day, and in the upper segments sixty-two days after the injury. On the other hand, in No. 4 the level of cord transection was the ninth thoracic segment, and a reflex response could not be obtained from stimulation, nocuous or otherwise, of the skin of the abdominal wall. Those segments of the isolated cord which lie nearest to the seat of injury appear to suffer more from "shock" than do those more caudally placed, and it is likely that in them actual structural changes occur, the result of concussion or hæmorrhage or both, from which they never recover. The reflex arcs at that level may possibly be permanently destroyed.

A course complicated by sepsis from the beginning, as in No. 5 of this series, may prevent the reappearance of any sign of reflex excitability of the abdominal muscles; and a febrile attack, as from pyelitis, arising during the clinical stage of reflex activity will diminish the ease with which they can be evoked.

The following types of motor reflex response from nocuous stimulation of the skin of the abdominal wall can be definitely identified:—

(1) *Rectus abdominis reflex.*—A scratch or a pin-prick applied to the skin which covers this muscle will evoke a motor response often limited to the rectus abdominis. The contraction is only a little delayed and consists of a tightening of the muscle, so that that part of the abdominal wall flattens quickly and relaxes again almost as quickly. There is no after-prolongation. The oblique muscles do not take part in the response unless the stimulus is of moderate intensity or the reflex excitability of the cord is high, so that the umbilicus is not pulled to the responding side and the flank bulges a little more during the rectus contraction.

Though that part of the muscle which is near the stimulated area contracts more strongly, it can be proved by palpation that the whole muscle actively responds. The faint shallow groove which defines the lateral margin of the rectus becomes more visible and straightens out.

Rectus contraction can be evoked, as already described, with flexion of the ipsilateral lower extremity from the receptive field of the flexion reflex. A scratch applied to the sole, if of sufficient intensity, originates impulses which not only stimulate the limb flexors and evoke flexion of the leg, but spread up the cord and excite contraction of the rectus abdominis of the stimulated side, i.e., an ipsilateral flexion reflex of the lower limb and trunk is elicited. The limb is reflexly drawn up out

of harm's way and, if the irritation is continued or is fairly strong, the flexor muscle of the abdominal wall is "called in" to help and it acts as an adjuvant in the protective movement. In my experience, the upper part of the thigh near the perineum is the focal area of the receptive field for this combined flexion movement.

Bilateral rectus contraction can be obtained by pricking or scratching the abdominal wall in the middle-line.

Nocuous stimulation of the perineum evokes contraction of both recti abdominis with bilateral flexion of the lower extremities. The recti take part in the "coitus reflex" to be described.

(2) *External oblique reflex.*—A reflex motor response confined to the lateral abdominal muscles of one side is obtained by nocuous stimulation of the overlying skin surface. A localized undulatory contraction of the external oblique muscle is obtained. It is somewhat vermicular in appearance and is slow to arrive. The line of the contraction follows the course of the external oblique fibres. This can be best seen by dragging the pin outward when the contraction runs from the edge of the rectus sheath outwards and upwards towards the costal margin. The rectus abdominis does not take part in the motor response unless the exciting stimulus is intense or reflex activity is great. A crossed response is not obtained, and, associated with this reflex, there is no movement of the toes or flexion at the knee.

(3) *Combined reflex response of both muscles.*—A mass-reflex of the ventral abdominal muscles can be obtained fairly early in most cases with high lesions. A firm scratch or a deep prick will evoke an apparently simultaneous contraction of the external oblique and rectus muscles so that the stimulated half of the abdominal wall flattens sharply and the patient is pulled to that side. Frequently the whole of the abdominal wall responds, the onset of muscular contraction of the opposite side being somewhat delayed, and both lower extremities may flex. This extensive reflex response may be obtained by sharply pricking the perineum, even with a stimulus of comparatively slight noxa, during the period of heightened reflex activity of the isolated cord segments.

A Composite Reflex Response which is obtained by stimulating the External Genitals.

Under this heading are grouped certain reflexes which have previously been described as isolated phenomena. They are erection of the penis, with or without emission of semen, the cremasteric and

bulbo-cavernosus reflexes and certain movements of the lower limbs and of the abdominal wall. I have found that, though they can be elicited individually, they form part of an extensive motor reflex response which involves the muscles of the abdominal wall and of both lower limbs, as well as the musculature of the genital organs. This reflex is obtained best from the penis, and by studying it in its entirety its "purpose" becomes more apparent.

During the first stage of muscular atony and reflex inexcitability the penis is soft and flabby and seminal emissions do not occur. The approximate date of reappearance of erection of the organ was recorded unfortunately in two cases only of the series. During the nineteen days that No. 5 lived, the penis remained flaccid and semen was never voided. In No. 3 turgescence of the penis was first noticed about the nineteenth day after the injury, following closely on the appearance of the flexion reflex and earlier than the tendon-jerks. In him the bulbo-cavernosus reflex could be evoked on the seventh day. In No. 4 any contact with the penis caused the organ to stiffen and the cremaster and dartos muscles to contract on the twenty-seventh day, while the flexion reflex was evoked on the seventh day and the tendon-jerks on the forty-second day. The evidence so far as it goes shows that the reflex arcs belonging to the external generative organs recover early, earlier than the extensor tendon-jerks, but not before the flexor muscles of the lower limbs or of the abdominal wall (recti abdominis) respond reflexly to appropriate stimulation.

(a) *Erection of the penis and seminal emission.*—At first the organ when handled only stiffens a little, but as the cord recovers its functional activity the response becomes more complete and erection may last for a few minutes. The passage of a catheter along the urethra, scratching or firmly rubbing the perineum or the upper parts of the thighs are adequate stimuli, but a response is most readily obtained by the procedure of cleansing the glans preparatory to passage of the catheter. Manipulation of the lower extremities and the repeated induction of flexor spasms in them evoked an erection of considerable volume in Nos. 1 and 3. As the penis becomes turgid, the testicles are retracted by contraction of the cremaster muscles and the scrotum is slowly tucked up. Seminal ejaculation sometimes occurs. Priapism is of usual occurrence in this stage of reflex activity.

(b) *Cremasteric and dartos reflexes.*—Retraction of the testicles can be elicited by nocuous stimulation (pricking, pinching or scratching) of

the perineum, of the upper part of the thigh on its inner aspect, of the scrotum or penis and sometimes by pulling the pubic hairs. As a rule, drawing up of the testes accompanies erection of the penis induced by touching or moving the preputial skin. A slow vermicular contraction of the dartos forms part of the cremasteric and penile response.

(c) *The complete reflex motor-response.*—(1) Nature of the stimulus. Stimulation of the penis and especially of the glans is the most effective stimulus. The reflex response can however be evoked, as in No. 1, by scratching the skin round the external genitals.

(2) Reflexogenous area.—The focal area where the threshold value of the stimulus is lowest is the prepuce and glans penis, but the receptive field extends from the penis and scrotum onto the abdominal wall for a varying distance, to the perineum, and to the upper part of the anterior and inner surfaces of the thighs. The intensity of the stimulus necessary to evoke the motor response increases with the distance of the locus from the glans penis.

(3) Motor-response.—The first response is in the penis. Whatever may have been the effective stimulus, the organ loses its flabbiness, stiffens a little and increases in volume. On continuing the stimulation, it soon becomes hard, tense and erect, the testicles are withdrawn towards the pubis by contraction of the cremaster muscles and the scrotum slowly curls up. Then the bulbo-cavernosus muscle and the abdominal recti contract sharply, the scrotum and testicles are drawn up and there is bilateral flexion of the lower extremities, or more rarely this is preceded by brief contraction of the quadriceps extensor and calf muscles. The adductors of the thigh fall into strong contraction. On cessation of the stimulus the penis becomes less tense, the recti abdominis relax and the lower limbs extend passively on the bed. The response is a phasic one of contraction and relaxation of the involved muscles. If the glans is gently squeezed for a few seconds the contraction phase lasts for that time, but if the stimulus is continued the abdominal and limb muscles as a rule relax before it is removed. The movements of the limbs and abdominal muscles follow at once on erection of the penis. Should the reflex be evoked by scratching the skin of one thigh, the motor reply as regards the abdominal recti and limb muscles is stronger on that side; but elicited from the penis, scrotum, perineum or the middle line of the abdomen the spasm is bilaterally symmetrical.

When the reflex occurred several times in succession in No. 1, sweating of the palms of the hands, of the skin of the trunk below the

fourth rib and of the lower limbs occurred and formed part of the general response. The skin of the rest of the body remained dry. In Nos. 1 and 4 of this series seminal emissions were not noticed to accompany the reflex response, but in No. 3 they frequently occurred.

The abdominal muscles did not take part in the response in No. 4, in whom the level of the cord injury was the ninth thoracic segment.

I have called this reflex motor-response "the coitus reflex"; it may be stated here that similar reflex movements have been observed by Goltz in the male spinal dog and that he believed them to belong to the act of copulation. He failed to obtain them on exciting analogous parts in the spinal bitch.

Vasomotor and Trophic Changes.

Œdema of the lower limbs.—Provided the lower extremities are kept in a horizontal position in bed they do not swell as a rule, though sometimes unilateral or bilateral œdema may develop, and especially if the course be febrile; it may persist for two or three weeks. The readjustment of vasomotor balance returns if the legs are lowered gradually, and ultimately the patient can sit up in a chair with his legs bent in the natural position for the whole day without appreciable swelling being evident in the evening.

An attack of pyelitis or other febrile disturbance, if it lasts for ten days or a fortnight, lowers temporarily the vitality of the vasomotor reflexes, as of the other reflex arcs, and if allowed to be pendulent the lower extremities will swell; but, with an improvement in the patient of his affected nervous mechanisms, the vasomotor balance soon becomes stable again.

Unilateral thrombosis of the femoral vein was a complication in two of the patients of this series. In No. 2 the left leg was affected, and in No 3 the right. It was accompanied by a rise of temperature which lasted in No. 3 for eight days. The œdema subsided in a fortnight to three weeks.

The skin of the paralysed parts, which during the first stage of flaccidity tends to be rather cyanosed or pale and cold, especially the skin of the toes, regains a good colour as the reflex arcs become patent, and, to the hand, it becomes normally warm.

Sweating.—The phenomena of sweating are fully considered in a paper by Head and Riddoch on p. 206 of the present number of this Journal. In consequence a brief description only will be given here.

Following closely on the appearance of reflex flexor activities in the legs comes sweating from the skin covering the paralysed parts. Up to this time the skin has been more than normally dry, and is often scaly in parts, with none of the gloss of healthy skin. The slightest scratch or abrasion has to be carefully attended to, for it quickly becomes septic. Unfortunately, a record of the approximate date of the onset of the sweating was made in three of the cases only, which were uncomplicated by fever during the early stages of the illness. In these the dates were twenty-first day (No. 3), thirty-second day (No. 4), and forty-fifth day (No. 1). In No. 1 it is true that the left half of the face and neck and the left shoulder and arm began to sweat at an earlier date, namely, about the twenty-second day after the injury, but somatic sensibility and motor power were unaffected in these regions. As the segmental level of the transection was the sixth thoracic, the sweating in this case from the left half of the upper part of the body can only be explained by postulating some irritation of the left sympathetic system above the level of section. It was a temporary phenomenon, disappearing about the forty-fifth day, when sweating from the trunk and legs began.

The sudorific area below the level of the lesion is determined strictly by the anatomical level at which the cord is divided, and, in consequence, the level at which the connector fibres of the thoracico-lumbar outflow are set free from the influence normally exerted on them by higher centres. It must always be kept in mind that, as Langley [24] has shown, only the effector or motor fibres of the autonomic nervous system—those fibres whose cells are stationed in the vertebral ganglia—are segmental, and that these cells, unlike those of the lower motor neurons of the central nervous system, do not intercommunicate. Each fibre of the connector system gives off collaterals to several ganglia above and below the one which it primarily enters, except in the lower dorsal region, where the connector neuron links up with cells in ganglia below the level at which it entered the sympathetic chain. Thus, in patients in whom the cord transection is above the tenth dorsal segmental level, sweating will occur, not only from the skin of the paralysed parts, but also from an area above the upper level of lost sensibility.

Of the cases of this series, the highest segmental level at which the cord was divided—namely, 3-4 thoracic segments—was in No. 2 and No. 3. They sweated from the arms and from the clavicles down to the toes, the head and neck remaining dry. In No. 1 the

level of section was the sixth thoracic segment, and he sweated on the palms of the hands, the lower extremities, and the trunk up to about the fourth rib. In No. 4, in whom the segmental level of transection was the ninth thoracic, the skin of the lower limbs and of the lower part of the trunk up to about 2 in. (5 cm.) above the pubis alone sweated.

The sweating tended as a rule to be more profuse from the upper part of the sudorific areas. Thus No. 2 was sometimes quite dry or only a little moist over the abdomen and lower limbs when his arms and chest poured with sweat.

Sweating, over the skin areas appropriate for each case, can be started off by stimulation of a wide receptive field. Thus vigorous involuntary flexor spasms or repeatedly induced flexion reflexes of the lower extremities will, as a rule, cover the sudorific area with moisture. Reflex evacuation of the bladder, if evoked several times in succession, as in washing out the organ, elicited profuse sweating in Nos. 1 and 2. Hyperidrosis could frequently be provoked in No. 1 by administering an enema, or by eliciting a "coitus reflex" from manipulation of the penis, and it frequently started off when the temperature of the skin was altered, as after a hot bath, or when he was put back to bed in the evening. It was more profuse as a rule during the night.

The extreme upper limit of the sudorific area in each case never alters, and when the sweating is not extreme it tends always to occur more profusely from the upper part of the area, fading away towards the feet.

In those cases, in which the highest level of injury was the third thoracic (Nos. 2 and 3), the size of the pupils did not alter with the onset of sweating.

No. 1 always knew when sweating was about to begin. He declared that it was preceded by a drumming in the head or a feeling of "fat-headedness."

As a rule fever and sudorific drugs, such as aspirin, produce hyperidrosis from the whole cutaneous surface of the body, as with Nos. 1 and 3; but if a rise of temperature occurs or salicylates are administered before the autonomic intraspinal arcs have recovered from "shock," that part of the body surface which later remains normally moist may be the only sweating area. Such was the case with No. 4 for the first thirty-two days of his illness.

Bed-sores.—During the stage of muscular flaccidity the skin covering he paralysed parts is colder than normal, pale and unhealthy looking,

and with slight constant pressure even soon becomes red and inflamed. It requires very careful and frequent attention to prevent the development of bed-sores. Once a sore does appear it become a hotbed of pyogenic and saprophytic organisms, and the sloughing process is apt to spread very rapidly.

With recovery of the reflex functions of the cord, however, the skin takes on a healthier appearance, becomes more normal in colour, and it is then possible to get sores to heal. But the onset of sweating or of pyrexia from urinary infection demands great attention to the skin and makes the nursing of the patient of primary importance. A septic sloughing bed-sore and recurring attacks of pyelitis constitute a vicious circle and keep the patient continually in a condition of toxæmia which soon terminates his life.

As far as possible, paraplegic patients should be nursed in the open air, and should be encouraged to exercise their arms and the upper parts of their bodies by raising themselves in bed with a pulley, and by propelling themselves along in a spinal chair. In this way the circulatory system is toned up and they may become very resistant to infection.

Bladder and Rectum.

Shortly after the caudal segments begin to recover their function, retention of urine and fæces becomes less complete. The bladder begins to void a little urine at irregular intervals, but it should be clearly understood that nothing analogous to a constant dribble is ever a clinical feature in cases of cord transection. As has been described by Head and Riddoch [21], the earliest phase of automatic action of the bladder and rectum is an irregular expulsion of a varying amount of urine and fæces due to active contraction of the detrusor muscles with simultaneous relaxation of the sphincters. Periodic automatic action becomes more regular as time goes on, and the amount voided by each reflex act increases and the residuum left in the bladder or rectum diminishes.

Automatic reflex action of the bladder lent itself more to systematic and accurate observation than did that of the rectum, and a considerable number of measured observations were carried out in conjunction with Dr. Head. They have been fully described in the communication referred to above.

In three of the cases reported here retention ended and automatic action began on the sixteenth, the twenty-second and the twenty-ninth

day. So far as our experience goes, the third week is about the average time of recovery of the bladder and rectal reflex arcs. Over-distension may play a great part in delaying the recovery of the reflex activity of these viscera.

The importance of early catheterization after the infliction of the cord injury, and of emptying the bladder at regular and frequent intervals, cannot be over-estimated. Over-distension of the organ not only prolongs the stage of retention by diminishing the excitability of the detrusor muscle to adequate stimuli, but endangers, at the very outset, the life of the patient; for then cystitis, often hæmorrhagic, develops early to terminate the life of the sufferer in a few weeks or at most months. And the risk of harmful stretching of the detrusor muscle is not avoided only by early and subsequently regular catheterization. Faulty technique employed in washing out the bladder is equally dangerous. Apart from the necessity for strict antiseptic methods, the irrigating fluid ought to be passed into the bladder only under very gentle pressure, a small quantity at a time. A large head of fluid is just as liable to prevent the recovery of the muscle by over-distending the bladder and to hasten septic infection of its mucous lining as delay in catheterization.

When automatic action becomes established we have found that the bladder in each case settles down to a fairly constant content at which it "fires off." Thus, No. 1 had a 400 to 500 c.c. bladder; in No. 2 evacuation occurred when the bladder contained from 250 to 290 c.c. of fluid, and in No. 3 when 350 to 390 c.c. had been passed in. The evacuation is forcible and, as a rule, continuous so long as it lasts. Care was always taken in such estimations of capacity that syphonage did not occur. A varying residuum was always found in the bladder until recovery of the reflex arcs became complete, when the total amount of fluid was expelled. Our method of washing out a bladder systematically was as follows: The amount which constituted the adequate stimulus for detrusor action was determined in each case. Then the cleansing of the bladder was carried out night and morning by pouring in the fluid till the reflex was evoked. This was repeated several times in succession. In this way the bladder was re-educated and perfect automatic evacuation was hastened.

It was found by experiment that stimuli applied to different parts of the body facilitated reflex evacuation of the bladder when the tonicity of the sphincter was overcome with a catheter. Thus a scratch applied to any part of the lower extremity, which evoked a flexor spasm, started active expulsion of urine in No. 1 when his bladder contained less than

half the quantity of fluid with which it usually "fired off." Evacuation was often not complete. Pinching or pricking the glans penis was almost equally effective, as also was gentle pressure applied to the hypogastric region. But often the most effective stimulus for facilitation was deep breathing. In No. 3 with the catheter *in situ* the back flow usually began when 370 to 380 c.c. of fluid had been passed into the bladder. By inducing a flexion reflex of the lower extremity it evacuated its contents completely at 180 c.c., and when the patient breathed deeply 70 to 80 c.c. were sufficient to evoke a reflex which emptied the bladder.

To give another instance, forty-five weeks after the injury, in No. 1, the bladder was reflexly voiding all its contents through a catheter when they reached 490 c.c. Scratching the sole of the foot provoked evacuation at 160 c.c., and with deep breathing it began when 25 c.c. only had passed into the bladder.

Thus extra-vesical stimuli capable of evoking a reflex from the spinal cord below the lesion can facilitate, in a very striking manner, the reaction of the bladder wall. But automatic micturition, such as occurred in each of the cases, demands not only contraction of the detrusor but also relaxation of the sphincter. Though more difficult technically, we were able to show by experiment that both could be induced by extravesical stimulation. A series of observations made on No. 1 may be quoted. This patient thirty-eight weeks after complete division of the spinal cord was passing a full quantity of urine into the bottle daily, so that each reflex act, made up of two components, namely, contraction of the bladder wall and inhibition of sphincter tone, was perfectly adapted to an end.

As mentioned above, the adequate endovesical stimulus for the reflex with the catheter *in situ* was a content of 490 c.c.; 400 c.c. of fluid were therefore allowed to run in and the catheter was gently removed. Deep breathing by the patient produced no obvious result, but on scratching the thigh 80 c.c. were voided automatically. When the bladder contained 200 c.c. we were unable to evoke reflex micturition by any stimulus, though the amount would have been more than adequate with the catheter in place. It would seem, then, that to induce the complete act, consisting of inhibition of the sphincter simultaneous with excitation of the bladder wall, the sum of impulses impinging on the motor paths must be greater than is necessary to provoke contraction of the detrusor alone.

The rectum reacts in the same way as does the bladder and the

necessary content for reflex action varies in each case. When an enema is given the amount of fluid sufficient to originate active evacuation depends on the quantity of fæcal matter that happens to be in the rectum. In No. 1 it varied from 2 to 8 oz. (56-224 c.c.), and in No. 3 from 2 to 10 oz. (56-280 c.c.). With an unloaded rectum 8 oz. (224 c.c.) was the almost constant adequate stimulus in the former, and 10 oz. (280 c.c.) in the latter. The evacuation is active and vigorous, the detrusor of the rectum contracting and the sphincter relaxing. Passive dribbling is unknown in my experience.

Sensation.

(1) *Spontaneous pains above the level of lost sensibility.*

The skin just above the upper limit of the anæsthetic area continues generally to be over-sensitive for some time after the reflex functions in the cord have reappeared, but it gradually becomes more normal. One or two small areas may, however, continue to be tender for a long time, but even these may finally disappear. As a stage in the recovery, superficial hyper-sensitiveness is frequently replaced by a feeling of constriction or tightness encircling the body at that level, or of pressure confined to one part—*e.g.*, over the sternum. The level of the tight feeling may alter after a time, as in No. 1. About six months after the injury it had shifted from about the level of the fifth rib to the level of the ensiform, and remained there for the rest of the time he was under observation. These abnormal root sensations were noticeably diminished when the patient suffered from a febrile attack of any kind; sometimes they disappeared altogether so long as the increased temperature lasted, or even after it had subsided.

(2) *Abdominal visceral sensibility.* A noteworthy feature was the degree with which abdominal visceral sensibility was affected according to the level of spinal transection. In Nos. 2 and 3 the cord was divided at the level of the third and fourth thoracic segments, and though both had attacks of pyelitis and cystitis with pyrexia, vomiting, and the characteristic furred tongue, yet they did not complain of abdominal discomfort or pain, or of tenderness on renal palpation.

Many patients with less severe injuries, such as No. 6, not only suffer from pain which they refer chiefly to the epigastric and umbilical regions during these attacks, but also are acutely sensitive to palpation of one or both kidneys.

In No. 1 the cord was transected at the sixth thoracic segmental

level. In him all abdominal sensations were referred to the upper epigastric region for a long time, though later he sometimes had a disagreeable sensation of fulness round the umbilicus and in the hypogastrium. When given a griping purge, he felt uncomfortable in the epigastrium for a little and then nothing. He was unable to localize his discomfort with any exactness. A gastro-intestinal attack gave rise to a burning feeling in the same region. So also if the abdomen was distended with gas the only discomfort or feeling of any kind referable to the abdomen was in the region of the stomach. He was conscious of deep pressure by hand only over the same limited area.

After a big meal or when he took a deep breath he felt as if there was a large solid lump situated deep in the epigastric angle pressing there. The disagreeable sensations in the upper abdomen were most noticeable when he had an attack of pyelitis, but they remained confined chiefly to the epigastrium. Less often they were referred to the hypogastrium. Deep palpation of the kidneys elicited only the response that the skin of the chest was being dragged down.

Throughout the time he was under observation he was unconscious of the passage of a catheter and of the administration of an enema.

When the level of section is in the lower dorsal region as in No. 4 (9th thoracic), not only are the majority of the abdominal visceral sensory paths intact, but the threshold value of stimuli which excite pain seems to be unusually lowered. The passage of a catheter along the urethra in this patient gave rise to severe cramp-like pains in the lower part of the abdomen, in the penis and testicles and round the upper part of the thighs. He had the feeling that an iron band encircled the lowered part of the trunk and the buttocks, and was being screwed up tighter and tighter as the catheter penetrated the urethra ; and he declared (though his eyes were covered) that he was aware of "something being put into the penis." He knew of course from experience that this pain was associated with catheterization and as a result he may in time have got to believe that he felt the instrument moving along towards the bladder. The reality of urethral pain was very difficult to prove or disprove by experiment, since stretching of the urethra gave rise immediately to the binding girdle feeling described above. Friction of the catheter on the mucous lining of the urethra seemed to be the most important cause of this pain, since with the instrument *in situ* the intensity of the pain diminished somewhat. It never quite disappeared however, so that mechanical stretching of the tube was probably in itself an effective stimulus. With removal of

the catheter the pain again became more agonizing. He dreaded catheterization so much that we were never able to obtain a complete series of observations on the reflex activity of his bladder.

Distension of the lower bowel with an enema gave rise to the same intense girdle sensations, with the burning feeling in the hypogastrium and at the base of the penis.

(3) *Sensations referred to the lower extremities.* With the appearance of involuntary flexor spasms in the lower extremities, the patients began to refer certain sensations to the legs. With their eyes shut they described the posture of these phantom limbs and the abnormal feelings they had in them.

The mental image which the sufferer has of his lower limbs varies from time to time and even within comparatively short intervals. He can visualize them, too, much more easily at one time than at another. Sometimes the visualized posture is described with a wealth of detail, while at other times the picture is blurred, fragmentary and hazy. The proximal part of the lower extremity from the knee to the thigh can be "thought of" more easily than can the distal part of the leg, except for the foot. The leg from the knee to the ankle may seem to the patient to be non-existent, and the foot may appear to be situated much nearer to the knee than normal. Thus No. 3 could describe his mental picture of the posture of his thighs and knees and particularly of his feet, but he had little or no idea of the legs between the knees and the ankles. His lower limbs seemed to stop abruptly at the knees, so that the feet lay quite detached in a position somewhat nearer the knees than was normal. The thighs were to him of ordinary length, but the legs had shortened if judged by the position he thought the feet were in. In my experience it has not been infrequent to obtain the description of apparent shortening of the legs from the knees to the ankles, and more than one patient has insisted that his feet seemed to be detached from him and that he had no idea of his calves.

The most common posture of the lower extremities described by the patient when his eyes are shut is one of flexion. The flexion is sometimes extreme, so that the knees feel as if they were being pressed firmly onto the abdomen and the calves on the back of the thighs, or the lower limbs may appear to the patient to be firmly tucked under him, the heels pressing on the buttocks. At another time the limbs may seem to be flexed, one crossed over the other. The knees may be elevated and the soles of the feet resting on the bed. They may be

separated or pressed close together; in fact innumerable postures are described, but the lower extremities invariably seem to be somewhat flexed at the knees.

Various aches and pains are referred to the lower extremities and they have a certain similarity in all cases, though they are more intense and varied the lower the level of the lesion. A very common sensation is a tired or aching feeling in the hamstring muscles, and in No. 4 (level of section the ninth thoracic segment) the tendons seemed to be drawn so tight that they vibrated and twanged like violin strings. This patient described the " strings " as extending from the testicles to the internal malleoli. He said: " I feel as if someone were pulling at my legs trying to get them straight, and the more they pull the tighter get the strings and soon I have to cry out with the pain." As described above he had frequently a girdle sensation which he referred to the buttocks, testicles and upper parts of the thighs. These parts he said seemed to be encircled by a broad iron band which was being screwed up tighter and tighter. But when the tense strings in the legs vibrated the iron band relaxed and the pressure diminished, to his great relief; for so intense was it at times that his face became drawn and haggard and he cried out with the pain. When a catheter was passed along the urethra he usually complained bitterly that the iron band sensation round the buttocks and testicles was intensified and was associated with a burning inflamed feeling in the lower abdomen and at the root of the penis. On being moved about in bed involuntary flexor spasms of the legs occurred which brought on the pains.

No. 4 often insisted that his right knee felt as if it had been wrenched and No. 1 complained of tingling under the toe-nails and in the calves of the legs.

It was noticeable in one case that during a febrile period knowledge of the posture of the legs and sensations referred to the legs were less clear and returned only when the fever had passed off.

(3) *Stage of Gradual Failure of Reflex Functions.*

If patients in whom the spinal cord has been completely divided keep in good health and remain free from intercurrent affections, the stage of reflex activity may go on for many months, as in the case of No. 1, and perhaps indefinitely. The isolated spinal segments seem to recover in an almost perfect manner from the depression which follows the withdrawal of the normal influences of centres further

headward, and the alterations in spinal cells of trophic character described by Sherrington in the monkey as "isolation dystrophy" [35] appear then to be of temporary nature. Decubitus, if not extensive and filthy, and mild cystitis, so long as the pus is discharged freely from the surface, affect the course little if at all. But as soon as the poisons are absorbed into the blood-stream, giving rise to septicæmia or toxæmia, the life of the patient is jeopardized and the functional activity of the reflex arcs deteriorates. One attack of pyelitis only too frequently leads to another of a more severe nature and ultimately the patient dies.

With each attack, reflexes become more difficult to evoke, some sooner than others. Those of the extensor system suffer first and the knee- and ankle-jerks disappear. Irradiation of impulses in the cord is prevented and soon a massive reflex response can no longer be obtained. The receptive field for the flexion reflex contracts more and more towards the focal area in the sole of the foot and ultimately only a feeble reaction, confined to the homolateral limb, can be obtained. The threshold value of stimuli is raised and stimuli of strong affective quality are alone adequate. Flexor spasms of the lower extremities gradually disappear.

The penis ceases to become erect and cremasteric and bulbocavernosus reflexes cannot be elicited; but, like the flexion reflex of the lower limb, they are destroyed with difficulty.

The muscles waste rapidly, and the skin becomes unhealthy and pale; large black sloughs appear unless the greatest care is exercised in the nursing of the patient.

The bladder diminishes in size with each attack of pyelitis and evacuates its contents with more and more irregularity and with less completeness. Retention of urine may return, but constant dribbling from a patulous condition of the sphincters occurred in No. 5 only, a short time before death.

It is worthy of note that the reflexes which are last to disappear are those which are excited by stimuli of strong affective quality, namely, the nociceptive flexion reflex of the lower extremities and the genital reflexes, and those which maintain tonic contraction in the sphincters of the bladder and rectum.

Chapter IV.—Comparison with Less Complete Lesions.

In cases of spinal injury where appreciation of somatic sensibility or voluntary power is not entirely lost, or where some control over the bladder and rectum is retained, the damage to the cord is obviously incomplete. But has the lesion of necessity destroyed all conduction when the parts supplied by the segments below the level of the injury are anæsthetic, when the muscles are completely paralysed, and when the bladder and rectum void their contents automatically? The evidence of post-mortem and histological examinations negative any such conclusion from the anatomical point of view. Are there, then, any clinical features which would lead us to conclude, in such cases, that conduction has not been entirely abolished? Clinically they cannot be differentiated during the stage of spinal shock, but in many cases reflexes in the paralysed parts return provided this period is tided over. Severe toxæmic complications, when present from the first, produce irrecoverable alteration in the caudal segments, and, in association with such changes, the reflexes to which we turn for the elucidation of the problem are suppressed.

In the systematic study during the past two and a half years of the reflex activities displayed by patients paralysed from wounds of the spinal cord, of all degrees of severity, certain points of difference have been noticed between the two types of case which are to be considered in this chapter. The description of No. 6, an example of partial injury to the spinal cord, will be contrasted with the picture of a case where we knew that the cord was totally divided.

It must, however, be clearly pointed out that all patients whose lesion is partial, and in whom sensation and voluntary control of the muscles of the paralysed regions of the body are abolished, do not correspond in every way in the reflexes which they present with such a clear-cut type as the one chosen. Many gradations are met with. In some the one lower extremity, for example, may, in its reflex actions, resemble closely the lower limb of a patient whose cord has been completely cut across, while the other lower extremity presents very different features. In such a case one half of the cord must have suffered more than the other, and several examples of this nature have come under my notice. Again, certain of the reflexes, which distinguish No. 6 so clearly, may not be obtained in others.

(1) *Relative Activity of Flexor and Extensor Reflex Arcs.*

The musculature of the lower extremities has been divided by Sherrington in animals and by Walshe in man into two great physiological muscle-groups : (1) Flexors or kinetic muscles which flex and shorten the limb and include the flexors of hip and knee, the dorsiflexors of the ankle and the muscles which move the toes upwards. (2) Extensor or static muscles which elongate the lower limb and, in man, maintain the erect posture. They are roughly the vasti cruris, the calf-muscles and the short muscles of the sole. The flexors subserve the function of *movement* and they go into contraction in a flexor spasm, in the flexion-reflex of the lower extremity and in the first phase of step. They depend for their activity on a reflex system whose synaptic junctions lie in the cord. The extensors, whose function is *posture* and which contract in the second phase of the step, appear to be activated by a double reflex system, part of which has centres in the cord, and part, the more important, in the brain-stem. The prespinal arcs of the extensor system are destroyed when the cord is completely cut across, as they are in the spinal animal, while in certain cases of incomplete injury they appear to function, as they do in the decerebrate animal. It would be expected then that the reflex excitability of the extensor muscles would be greatly affected by the separation of the lower centres from the higher ; and Sherrington has shown by comparing the decerebrate and the spinal animal that decerebrate rigidity or hypertonus, a manifestation of extensor activity, so prominent a feature of the one, is much diminished or absent in the other. What has been lost, by making the animal spinal, is plastic or reflex tonus. It is to be found only in those muscles which subserve the maintenance of posture, anti-gravity muscles, and in the limbs they perform the extension phase in walking and keep the animal erect when standing.

As the animal scale is ascended plastic tonus suffers more and more by spinal transection. Thus the spinal cat or dog can stand, the hind limbs supporting the superincumbent hind quarters, for sometimes as long as half an hour. But they are not to be depended upon and are prone to sudden lapses at any time. The spinal monkey is more helpless than the dog, for he cannot stand at all.

Now Walshe, [42] in his able study of spastic paralysis of the lower limbs, has confirmed Babinski's view [2] that there are two clinical types, "paraplegia in extension" and "paraplegia in flexion." By a comparative analysis of the reflexes which they display, he has

demonstrated conclusively that the essential difference between the two types is that while in the extended form both extensor and flexor groups of muscles are in a state of heightened reflex activity, in the flexed form only the flexors show this, extensor reflex activity being diminished or absent. He agreed with Sherrington that the reduced extensor action is due to the interruption of prespinal paths other than the corticospinal.

The thesis I wish to put forward in this chapter is that by studying the activities of the flexor and extensor reflex arcs of the lower extremities, it is frequently possible to say whether conduction in the spinal cord has been completely destroyed or not. We know that total transverse division of the cord gives rise to the symptom-complex of "paralysis in flexion" with its outstanding characteristic, diffuse unantagonized flexor action, while many partial lesions are associated with "paralysis in extension," a more controlled and subdued clinical state.

Let us then compare, from this point of view, the signs and symptoms presented by certain partial injuries to the cord, taking No. 6 as a type, with other cases of my series in whom the injury was known to be complete.

(a) Involuntary movements of the lower extremities.—The involuntary spasms that convulse the lower limbs of spinal man have been described in the previous chapter. As the cord segments shake off the depression which follows their sudden isolation, the flexor muscles begin to show signs of life. Their contractions are at first feeble and gentle and are unable to displace the heavy limb and to combat with gravity. But soon they gain strength sufficient to bend the knee and to jerk the foot and toes upward spasmodically, and a time ultimately comes when they dominate the patient who is helpless to control them. The slightest movement of the bed-clothes, the mere bending of the head or the gentlest cough is sufficient to provoke flexor spasms of one or both lower limbs and of the abdominal wall so sudden and violent that the sufferer grunts from the forced expulsion of air from the chest and can with difficulty prevent himself, by clinging with his arms, from being jerked out of bed.

The spasms in such a case are typically flexor, and though intermittent they consist of only one active phase, namely, that of flexion. The extension of the limb which follows is passive and due to relaxation of the flexor spasm. In only one patient (No. 1) were extensor movements observed in one leg complementary to primary flexor spasms in the other; in him they occurred occasionally after nine

months of excessive reflex activity, but, throughout, flexor spasms were dominant.

In striking contrast to this were the movements of the lower limbs of No. 6. Gentle flexion of one limb, consisting of bending of the knee and dorsiflexion of the foot and toes, was always accompanied by extension of the knee and plantar extension of the foot and toes of the other limb. Then the flexing limb extended actively and the other flexed and so on, alternately moving up and down for several minutes at a time, each change in posture being brought about by reflex muscular contraction. They closely resembled in their diphasic character the steppage movements of the spinal dog described by Sherrington, Goltz and others. There was nothing wild and disorganized about them and they never troubled the patient. If he closed his eyes, he was quite unaware that they were going on. Further, involuntary movements of the lower extremities are relatively infrequent in this class of case, but when they do occur they are either alternating in phase in the two limbs or consist of a sudden increase of extensor tone, usually in both at once, producing perhaps no alteration in their posture except a downward movement of the feet and toes. In the one case there was a fierce, uncontrolled flexor movement of one or both lower limbs and of the abdominal wall, worthy of the name of "spasm," with no active extensor phase and with no resemblance to locomotion. It reminded one strongly of a furious withdrawal of the limb from harm. The other, which had two components, a flexor phase followed by an extensor phase, was more controlled, showing a higher degree of co-ordination in that both lower limbs took part in each movement, the one in the opposite phase to the other. The muscles of the abdominal wall were never involved in the movements.

(*b*) *The posture of the lower limbs.*—In patients in whom the section of the cord was known to be complete, the posture of the lower extremities in the resting state, during the stage of heightened reflex activity, was as a rule one of slight flexion at hip and knee, adduction and usually rotation outwards of the thigh and dorsiflexion of the foot and toes. In the class of partial lesion, however, to which No. 6 belongs, the lower limbs are usually extended at hip and knee with the feet and toes pointing slightly downwards.

Whatever be the extent of the injury, the patient is usually aware that he has lower limbs and he can describe their positions as they seem to him. With his eyes covered, the patient, whose cord is

totally divided, almost invariably thinks that the posture of his lower extremities is one of flexion at hip and knee, the limbs being bent up under him or more commonly with the soles of the feet resting on the bed. The posture may differ slightly in the two limbs and the degree of flexion of the joints usually varies from time to time. On the other hand, the lower limbs of the patient with a less severe injury to the cord, which are "in extension," are constantly described by him as lying straight out in front of him and never as being bent.

(*c*) *Reflexes evoked by stimulation of the lower extremities.*— Whatever the extent of cord damage may be, the motor response obtained by the application of affective stimuli to the sole of the foot is invariably a flexion reflex of the lower limb. But the withdrawal movement, in some of its characters, may differ, to a noteworthy degree, according to whether conduction has been completely or partially destroyed.

The motor response described as typical of the grosser disturbance at a time when the excitability of the reflex arcs is high, is a vigorous movement identical with the flexor spasm. When evoked by a stimulus of moderate intensity, such as a scratch from the sharp point of a pin, it is accompanied by an almost simultaneous spasm of the abdominal wall, usually of the homolateral half, but sometimes of both sides, and after a brief delay, by flexion, chiefly at hip and knee, of the contralateral lower extremity. A wide motor field is thus set into vigorous contraction, and the movement may be so sharp and fierce as to jerk the patient down the bed.

In many patients, in whom the disturbance of conduction is less complete, and in whom the reflex conditions are equally favourable, the response evoked by a similar stimulus of the same place is not so powerful and unantagonized. That evoked in No. 6, for example, consisted of a bending movement at hip, knee, ankle and toe joints of less amplitude and violence. Its reflex accompaniment in the crossed limb was, without exception, active extension at hip and knee, sufficient to force down the limb if passively bent, and plantar flexion of foot and toes; and, moreover, it was, as far as could be judged, identical in time with the induced flexion reflex. The accessory reflex reply in the contralateral lower extremity involved the muscles antagonistic to those usually excited in a case of complete cord transection and the reaction was simultaneous in the two limbs. More intense stimulation of the sole was required to involve the abdominal muscles in the reflex response.

It is true that in Nos. 1 and 2, patients whose lesions were total, palpable contraction of the crossed extensors sometimes accompanied an induced flexion reflex of the other lower extremity, but this response was by no means constant, and it was so feeble that usually it could not be seen nor could it actively extend the limb. A crossed flexor spasm was, on the whole, the more common reaction. In all other cases which I have observed, the crossed reaction was invariably of the flexors.

Another feature which distinguished the flexion reflex of such cases as No. 6 from those of more extensive damage, is the duration of after-contraction and the character of the second phase of the reflex. It was noted in the preceding chapter that the reflex contraction of the flexors outlasts for a short period the application of brief stimulus of moderate intensity. The response may attain its height just after the stimulation from a quick scratch has ceased. But it soon runs down with a rapid and usually tremulous decline, and lasts at longest a few seconds only. With weak or moderately weak reflexes there is hardly any after-contraction. The flexors contract quickly and almost immediately relax. Moreover, the return of the limb to its original posture of extension, or more often of slight flexion, is brought about not by active contraction of the extensors, but by the mere weight of the limb and relaxation of the flexors. The flexion reflex of the lower extremity of a patient in whom conduction is completely abolished is a uniphasic movement, only one set of muscles being employed from beginning to end of the reflex effect.

In the type of partial lesion under consideration, the flexion movement of the limb may attain the greatest amplitude after a brief stimulus is removed, but it is maintained for a longer time, the difference being sufficient to be detected by the eye, and the relaxation which follows is slower and more leisurely. And, further, the second phase of a flexion reflex evoked by a stimulus of moderate intensity, is frequently well-marked extension of the limb. The reflex is diphasic. I have never observed a rebound extension, or even palpable contraction of the extensors following on reflex flexion in the lower extremity of a patient whose spinal cord has been entirely separated from headward centres.

The reflex effect which Sherrington [36] has described in the decerebrate and the spinal dog, and Baglioni [3] in the spinal frog as the "extensor-thrust," could constantly be evoked in No. 6 and in similar cases. "In the spinal dog, where well marked, it is often elicited

by even lightly stroking the skin behind the plantar cushion with the edge of a piece of paper. It is more certainly evoked by pushing the finger-tip between the plantar cushion and the toe-pads, especially when the hip and knee, not necessarily the ankles, are resting passively flexed" ([33] p. 67). In man it can be evoked by pressing the foot gently upwards with the palm of the hand when the lower limb has been passively flexed, and is lying resting on the bed. The active contraction of the quadriceps cruris and the muscles of the calf, which follows this proprioceptive stimulus, straightens the limb out sharply.

This reflex depends for its presence on a condition of heightened tonus in the extensor muscle-groups, and, in consequence, it could not be evoked in any patient where conduction was completely abolished. In No. 1 the foot was sometimes thrust sharply downwards if the calf-muscles were suddenly stretched by jerking up the foot, and three or four clonic jerks were obtained. But contraction of the extensor muscles could not be obtained by increasing the tension of the calf-muscles gradually when the limb was resting in a posture of flexion.

Another reflex, which, in my experience, can never be elicited in spinal man, is homolateral extension of the lower extremity in response to stimulation of the base of the limb or of the perineum. The receptive field for the flexion reflex in uncomplicated cases of total transverse lesion, when the isolated segments have completely emerged from "shock," extends from the sole of the foot to the groin, the perineum and the abdominal wall. Nociceptive stimuli applied either to the skin or to the deep structures of this field are capable of evoking a flexion reflex, and no other. In marked contrast is what obtains in certain cases of partial injury to the spinal cord. In No. 6 the reflexogenous area for the flexion reflex was limited to the periphery of the lower extremities. Nocuous stimuli applied to the sole of the foot or to the leg as far as the knee evoked a typical flexion reflex of the limb with an accessory crossed extension reflex. From the neighbourhood of the knee, however, a varying reaction, sometimes flexion, sometimes extension, was obtained in the limb stimulated, while the response in the contralateral lower extremity remained constant. Stimulation of the thigh, especially of its anterior and inner aspects, of the groin and perineum gave a bilateral reflex response consisting of strong extension at the knees and feet and downward movement of the toes. I was unable at any time to evoke a flexion reflex as a primary motor effect from exciting this field, which comprised both skin and deep structures. Asymmetrical in the two lower extremities when evoked from the

peripheral parts of the reflexogenous area, the response was, as far as could be judged, identical in both as regards the vigour and extent of the contraction when the perineum was pinched or scratched. The external genitals formed the focal area of the receptive field which extended down the inner and anterior aspects of both thighs and on to the abdominal wall, reaching in the middle-line to within 2 in. (5 cm.) of the umbilicus. The threshold value of the stimulus decreased from the periphery of the field towards the penis. Nocuous stimuli were as a rule alone adequate in the thighs and abdominal wall, but on moving the prepuce backwards and forwards over the glans penis a complete motor response, which may be called "the coitus reflex," could be evoked.

This reflex is a perfectly co-ordinated diphasic motor response to stimuli of a particular quality and closely resembles the act of copulation. The limb movement was invariably extension, never flexion. Now when the penis was stimulated in a similar manner in cases of complete transection of the cord, a composite reflex effect was obtained which differed from that described above in one important characteristic. While the external genitals and the muscles of the abdominal wall responded in the same fashion, instead of tonic extension of the lower extremities, a bilateral flexor spasm was the associated movement. As a rule the motor response in the flexors of the limbs does not absolutely synchronize with that of the rest of the muscular field involved and in No. 1 very brief contraction of the quadriceps cruris, palpable but not visible, occupied the short interval that elapsed before the flexor spasms appeared. But participation of the extensors could not be detected in any other patient examined and active extension of the lower extremities was never obtained.

To recapitulate, so far as my present experience goes, the receptive field for the flexion reflex of the lower limb in patients in whom conduction has been abolished and in whom the segments caudal to the lesion are in a high state of reflex excitability, covers the whole limb and extends on to the perineum, the external genital organs and to the abdominal wall. In them homolateral or bilateral extension of the lower extremities can never be evoked by stimulation of the skin and deep structures of the abdomen, of the penis, scrotum or perineum or of the thighs, nor by gently pressing on the sole when the limb is passively flexed. On the other hand, certain patients suffering from a less gross injury show extensor reflexes of one or both lower limbs when these areas are excited.

Sherrington ([34] p. 33) describes a similar homolateral extensor reflex in animals occurring on nocuous stimulation of the base of the limb or of the perineum. Walshe was ([42] p. 298) able to evoke it in a few of the cases of spastic paralysis of the lower limbs which he examined, but he failed to observe any crossed reflex accompanying it.

The knee-jerk, obtained in No. 6 and in similar cases, presented a feature worthy of mention in that it was not detected in the jerk evoked in cases of total transection of the cord. The ease with which it could be obtained by tapping the patellar tendon in the usual manner may not be greater or only slightly so in the one group than in the other; but whereas in cases of total transection and functional division the relaxation of the quadriceps muscle, which forms the second phase of the response, is sluggish, occupying a few seconds, in those where the cord has been functionally divided it is as quick as the contraction producing the jerk of the limb. This difference, which can be quite definitely seen, has been noted by Sherrington [37] as constituting an important distinction between the phenomena obtained in decerebrate and spinal animals. He believes that the longer relaxation period is due to the presence of postural tonus in the extensor muscles of the knee and that it gives a much more reliable indication of hypertonus than does the amplitude and vigour of the jerk.

In comparing, then, the characteristics of reflexes obtained in patients whose cords were known to have been completely divided and in those in whom the postural arcs remained patent, the difference in the relative excitability of the flexor and extensor reflexes is much greater in the one than in the other. The clinical picture of the former conforms more or less closely to the "paraplegia in flexion" and of the latter to the "paraplegia in extension," of Babinski and Walshe. The added extensor phenomena are due to the preservation of proprio-spinal paths by which the central nervous system headward to the lesion is capable of influencing the activities of the part caudal to the lesion. These tracts Walshe believes to be extra-pyramidal and to arise in the brain-stem. The man in whom conduction has been abolished resembles in the reflex actions of his paralysed parts the condition of the spinal animal, while the other resembles more the decerebrate animal. But many patients are met with who form, in their condition, transitions between the two syndromes; and, in them, the presence or absence of the phenomena about to be described will be of great assistance in gauging the severity of the lesion.

(2) *Facilitation of Bladder Activity.*

A characteristic feature, in favourable cases of destruction of the postural arcs, is the ease with which impulses originating from a stimulus irradiate in the cord, so that the response evoked involves a wide muscular field. For example, in such a case as No. 1, nociceptive stimuation of the sole could excite the following effects: vigorous flexion of the homolateral lower extremity, flexion or weak contraction of the extensors of the crossed limb, spasm of the ventral abdominal muscles, evacuation of urine by the bladder and profuse sweating from a skin area which depended on the level of the spinal injury. The impulses excite contraction of muscles belonging not only to the skeletal system but also to the involuntary system.

To obtain this massive response in its complete form, the isolated cord must be in a condition of high functional activity, as obtains when the effects of spinal "shock" have disappeared and when the patient has not been subject to toxic febrile complications, at any rate for some time. Now, under approximately similar conditions as regards functional activity of reflex arcs, and intensity, quality and locality of the stimulus in such cases of partial lesion as No. 6, the response evoked will be less extensive. A flexion reflex of the stimulated limb of less wild and uncontrolled character will be accompanied by active extension at hip and knee and plantar flexion of the foot and toes of the contralateral lower extremity, and sometimes, but by no means always, by contraction of the rectus abdominis of the homolateral side. There the effect stops, except that, as the second phase of the reflex in the lower extremities, active extension may follow flexion of one limb and flexion follow extension of the other. But, however intense the stimulus may be, hyperidrosis and expulsion of urine is not obtained.

The ease with which reflex evacuation of the bladder can be influenced by other activities of the spinal cord can be well seen from the series of observations made on No. 3, sixty-one days after he was wounded. Stimulation of almost any paralysed region of the body provoked evacuation of urine at a smaller bladder content than that usually necessary. We found that deep breathing was one of the most potent of these facilitating stimuli and in the patient under consideration its effects were very striking. Conversely, automatic evacuation of the bladder was frequently accompanied by flexor spasms of the lower extremities.

In all cases of partial lesion, in whom primary extensor reflexes

are present, the bladder cannot be influenced at all by extraneous stimuli. Thus the bladder of No. 6 reacted to an average content of 250 c.c., and deep breathing and scratching the sole or any part of the lower extremities and abdomen were impotent to excite reflex evacuation at a smaller volume. Conversely, the act of automatic micturition never induced reflex movements of the lower limbs.[1]

In all my cases of total transverse lesion, which reached the stage of reflex excitability, impulses entering the cord spread with ease and excited a co-ordinated response in muscles which belong to both voluntary and involuntary systems; but it would seem from our results that the less the degree of injury to the postural system the more are impulses inhibited from spreading to effector systems other than those corresponding to the afferent paths along which they have travelled.

The association of a high degree of activity of the extensor or postural reflex arcs with inhibition of reflex spread is very significant. In another communication [21] the view has been expressed that it gives the clue to the meaning of "local signature" in such cases of spinal injury as No. 6.

The "extensor thrust," ipsilateral extension of the lower extremities from nocuous stimulation of the thigh and involuntary steppage movements depend on the presence of reflex tonus in the extensor muscles, and on the integrity of the proprio-spinal arcs of the postural neural mechanism. This reflex system can act without the intervention of consciousness, and, when intact, the lower extremities no longer perform reflex movements alone but react together in response to somatic stimuli. Thus, on scratching the sole of the foot, instead of a uniphasic flexion movement of the lower limb, diaphasic movements of both lower extremities in opposite phase are evoked. Whereas, in a case of complete transection of the cord, the whole response consists of flexion of one limb and either flexion or extension of the other, in No. 6 flexion of the stimulated limb, invariably accompanied by crossed extension, was followed by active extension of the first limb and flexion of the other, movements which simulate closely those of locomotion. In other words, postural activities have been superadded, which control the diffuse protective reflexes of the spinal level. Flexion only results from stimulation of some part of the lower extremity below the knee and active

[1] It must be clearly understood that the pre-spinal arcs of the postural system may be so gravely injured that primary extensor reflexes cannot be obtained and facilitation of bladder activity is present although sensation and voluntary power are not entirely abolished. A case of this sort has been described by Head and Riddoch ([21] p. 197).

extension is evoked from pressure applied to the sole of the foot. So, also, evacuation of the bladder cannot be obtained in association with the protective reflex movements of the lower extremities. Reflex reactions exhibit a more perfect adaptation to the quality and locality of the stimuli which excite them. They represent a higher order of central control.

To summarize, by systematically studying, in the stage of reflex activity, the relative activities displayed by flexor and extensor reflex-arcs and by investigating the phenomenon of facilitation, it is usually possible to determine whether the spinal cord has been functionally divided or not in those cases where all voluntary muscular control and sensibility are abolished in the parts supplied by the cord below the level of injury. Features which are exhibited by many cases of partial lesion and which I have failed to detect in undoubted cases of complete anatomical transection are the following:—

(1) Involuntary flexor movements of the lower extremities, which are followed by extension due to active contraction of the quadriceps cruris and calf muscles ("rebound extension" of Sherrington). These movements in their phases are often alternating in time in the two limbs, flexion of one limb being accompanied by simultaneous extension of the other, thus resembling closely the mechanism of stepping.

(2) Extensor thrust of the lower extremity, which has been passively flexed, in response to pressure applied to the sole of the foot just over the heads of the metatarsal bones so that the calf muscles are gently stretched.

(3) Homolateral or bilateral extension of the lower limbs evoked by stimulation of a wide receptive field comprising the anterior and inner aspects of the thighs, the groins and perineum, the lower part of the abdominal wall and the external genital organs which form its focus, in that there the threshold value of the stimulus is lowest.

(4) Prolongation of the second or relaxation phase of the knee-jerk.

On the other hand, facilitation of bladder activity by extravesical stimuli does not occur when these conditions are present.

The reflex activities of spinal man closely resemble those of the spinal monkey and those of cases grouped by Babinski and Walshe as "paralysis in flexion." Those of patients who have sustained less severe injury, and in whom postural arcs are patent, are more akin to the reactions of the decerebrate animal and to cases of "paralysis in extension."

Chapter V.—Consideration of Reflex Activity.

(1) Factors which influence it.

(a) The Quality, Summation, Intensity and Locality of the Stimuli.

The experimental work of physiologists on animals, and, in particular, the epoch-making researches of Sherrington on the spinal and decerebrate cat, dog and monkey have thrown a flood of light on the nature and meaning of reflexes and have elucidated many of the principles which underlie them.

Different modes of cutaneous and deep stimulation (electrical, mechanical, thermal, chemical) are capable of evoking spinal reflexes, but the form of the movement may differ with the nature of the excitation. For example, Baglioni [4], who analysed the reflexes of the "spinal frog," showed that gentle pressure with the finger or any blunt object on the sole of the foot excites an extension reflex of the hind-limb with spread of the toes of the same foot, so that the web presses against the impinging finger. Painful stimulation, e.g., pricking with the point of a pin or compression with forceps of the same point of the skin, evokes the opposite reflex, namely, flexion of the hind-limb and contraction of the web, so that the foot is withdrawn from the stimulus. Similar reflex reactions in response to stimuli of the same quality are well known, from Sherrington's descriptions, to occur in the spinal dog. Thus certain reflexes such as the "scratch-reflex" can be elicited with specific stimuli only.

The character of the reflex is also influenced by the intensity of stimulation. A weak stimulus excites as a rule a few efferent impulses, while those from a stronger stimulus spread to many efferent channels, though, according to Sherrington, there is no strict relation between the strength of the stimulus and the extent and duration of the reflex.

The locality of stimulation is another important factor in determining the character of reflex movements and the internal conditions of the reflex arcs influence most of all the degree of the reactions. The extent of the muscular field involved in the reflex is also influenced by the physiological processes of inhibition and facilitation, by which is meant the influence exerted on the reflex activity of one part by other portions of the nervous system with which it is in connexion.

The question we have to consider is whether these conditions, which are known to govern reflex activity in spinal animals, apply likewise to those displayed by man after division of the spinal cord.

Influence of the quality of the stimulus.—Sense-organs through the evolutionary ages have become highly specialized for the reception of particular groups of physical stimuli leading to a more complete adaptation to the environment. Sherrington says ([33] p. 12): "The function of the receptor is to lower for its reflex arc the threshold value of one kind of stimulus and to heighten the threshold value of all other kinds of stimuli for that arc; it thus confers selective excitability on the arc."

The quality of the stimulus is one of the most important factors in determining the type of reflex movement that is to be made. In the spinal dog a scratch applied to the sole of the foot evokes a response in the hind-limb exactly opposite in phase to that which follows gentle pressure on the toe-pad. Both are perfectly co-ordinated movements, but in the one the foot is withdrawn from the nociceptive stimulus, while in the other it is thrust against the thumb, as it is against the ground in the first phase of locomotion. Each reaction is adapted to the quality of the stimulus applied to the part.

Physiologists have shown that stimuli, which in the intact individual have a strong affective tone, are peculiarly efficient for evoking reflex movements in spinal animals and so I have found them to be in spinal man. The most potent of all are stimuli of nocuous character such as pricking or scratching with the point of a pin, faradic currents of moderate strength, and firm squeezing of the tissues.

The only purposive reflex which I have been able to obtain from cutaneous stimulation of the lower extremities in man, when the spinal cord has been completely divided, is the flexion reflex. It can be evoked most easily by affective stimuli. This reflex response is flexion at all joints including, as Walshe has abundantly proved, the Babinski toe-phenomenon. As the excitability of the cord increases, the degree of noxa necessary to elicit it diminishes. In all the cases observed, where the second stage of functional activity was reached, a tickling stimulus was adequate, but only for the sole, the focal area of the receptive field. The farther away from the sole the site of stimulation, the greater had to be the nocuous quality of the stimulus necessary to evoke the response. The flexion reflex, in the muscles involved in the movement, in the nature of the exciting stimuli and in the focal area of the receptive field, is strictly comparable with that obtained by Sherrington in the hind-limb of the spinal dog.

I have not been able to evoke in any case of complete cord transection in man the antagonistic reflex movement of extension of the hind-limb, which he describes in the spinal dog as occurring when

gentle pressure is applied to the foot-pad, a stimulus with little or no affective tone; but it was obtained in a group of cases of less severe damage.

Stimuli which excite the external genital organs are of strong affective quality and they are effective in provoking reflex movements. Erection of the penis readily follows any gentle rubbing of the organ or a to-and-fro movement of the prepuce over the glans. The complete motor response to such a stimulus has already been described. On the other hand, pricking, scratching or nipping the part, stimuli which are very potent in facilitating reflex evacuation of the bladder, quickly cause the erected penis to become relaxed and flabby.

Again, the appropriate stimulus for automatic micturition and defæcation is slight stretching of the detrusor muscles of the bladder and rectum; and to elicit the knee-jerk the tension of the quadriceps cruris muscle must be suddenly increased by a sharp tap on the tendon.

A stimulus to be effective must approach the normal type adequate for that particular reflex movement. It is true that reflex evacuation of the bladder can be hastened by nociceptive stimulation of the sole or penis, and, though due to an abnormal ease of irradiation of impulses in the cord, it is, after all, the prototype at the spinal level of the involuntary micturition of a very sensitive child who is disturbed by an intense and sudden fear. There can be little doubt that all stimuli of strong affective or emotional tone are peculiarly liable to excite motor discharges in the visceral reflex arcs.

Summation of stimuli.—As in laboratory experiments on animals, it was found that a stimulus in itself subliminal, if repeated, will evoke a reaction. Thus a single prick of the sole of the foot might not provoke reflex contractions of the flexors of the lower extremity, but three or four similar pricks applied in quick succession would elicit a flexion reflex. Again, a single flexor spasm of the lower limb or a single reflex evacuation of the bladder or rectum may have no appreciable effect on the moisture of the skin; but several such motor discharges, if occurring at not too long intervals, are followed by hyperidrosis of the skin area peculiar to a spinal lesion at that particular level.

Intensity of the stimulus.—As a rule, a strong stimulus evokes a more vigorous reaction than a weak stimulus. Thus a gentle tap with a hammer on the patellar tendon may elicit a contraction of the quadriceps cruris muscle of sufficient strength only to tighten the lax tendon, whereas a more vigorous application will be followed by extension of the leg on the thigh.

From investigations on the flexion reflex in spastic paralysis of the lower limbs in man, Walshe [42] agrees with Sherrington's results in animals that the hamstring muscles form the motor focus of the reflex. He arrived at this conclusion from the examination of three patients with hemiplegia from cerebral tumour, and of one patient suffering from an acute myelitis, which he believed to be, from Bastian's standpoint, a total transverse lesion. The minimal motor response in these cases to stimulation of the sole was hamstring contraction alone.

In none of the cases examined of undoubted complete anatomical transection of the cord was I able to obtain this minimal response to a weak stimulus, though I have observed it in other cases of spinal injury where I had not the opportunity of ascertaining the extent of the damage, at operation or at autopsy. It may be that in "spinal" man "local signature" is so far reduced that all muscles belonging to a "type-reflex" contract in response to a stimulus just liminal; or possibly my experience has been too limited. What definitely happens, however, is that weak excitations evoke as a rule a feeble reaction in the flexor muscles of the limb and a stronger stimulus produces a vigorous spasm. But intense stimulation not only affects the vigour and amplitude of the reflex response but it also increases the extent of the muscular field involved. Impulses spread in the cord to common paths other than those belonging to the type-reflex and give rise to what we have called a "mass-reflex" ([21] p. 220). A simple flexion reflex of the lower extremity follows a prick applied to the sole, but a firm scratch evokes, in addition, spasm of the ventral abdominal muscles and flexion of the contralateral lower limb. If stimulation is continued, its effect may go farther and excite evacuation of the bladder, and an outburst of sweating from a skin area varying with the level of the spinal section. The power of a stimulus to originate a motor effect in a wide muscular field depends not only on its strength but also on the suddenness of its application. Both factors combine to give the centrifugal impulses sufficient intensity to break down the synaptic resistences of a large number of allied reflex arcs. But however extensive the motor reaction may be, the combined movement is always orderly and co-ordinate. The "mass-reflex" illustrates Sherrington's principle that allied reflexes mutually reinforce one another while those that are antagonistic to their proper action are inhibited.

Rosenthal (quoted by Sherrington [38] p. 829) has proved that there is a distinct relation between the intensity of the external stimulus and the latent time of the spinal reaction, the latter becoming

shorter as the former is increased. I have several times verified this at the period when the cord was passing out of the condition of "spinal shock," or when a patient, whose reflexes had been previously active, was recovering from a toxæmia, the result of urinary infection. In one patient, for example, a week after his injury, slight flexion at hip and knee and dorsiflexion of the foot with down-going toes could be obtained by nocuous stimulation of the sole, but the latency of the response from a weak stimulus was appreciably greater than of that from a strong stimulus.

Influence of the locality of the stimulus.—The seat of the stimulus is a factor in determining the character of the reflex movements evoked. Sherrington's ([38] p. 820) expression of the rules of spatial proximity are as follows:—

"(1) Broadly speaking the degree of spinal reflex intimacy between afferent and efferent spinal roots varies directly as their segmental proximity.

"(2) Taken generally, for each afferent root there exists in immediate proximity to its own place of entrance in the cord (e.g., in its own segment) a reflex motor path of as low resistance as any open to it anywhere. Further, in response to excitation, of even approximate minimal intensity, a single afferent root or a single filament of a single root evokes a spinal discharge of centrifugal impulses which tends to occur not only through its own efferent root but through more than one efferent root, i.e., is pluri-segmental, and this holds especially true in the limb regions."

He maintains that the influence on the nature of the motor response of the locus of the stimulus furnishes a large part of the direct evidence of the "purposive" character of spinal reflexes.

Though gross variations in the reflex movements evoked, such as are obtained in spinal animals, e.g., in the scratch and flexion reflexes, are not evident in spinal man, yet slight differences are observed in type-reflexes on irritating separate points in the receptive fields.

Thus the reflexogenous area for the flexion reflex of the lower extremity extends from the sole to the abdominal wall, and from any part of this field a type reflex can be elicited. But in that evoked from the abdomen and from the groin, flexion at hip and knee and adduction of the thigh are the prominent movements, and the feet and toes may be affected slightly, or even not at all. On the other hand, dorsiflexion of the foot and up-going toes are outstanding features of the reflex effect when the sole is the part stimulated.

Again, a mass-reflex consisting of retraction of the abdominal wall and bilateral flexor spasm of the lower extremities, is approximately symmetrical when the locus of the exiciting stimulus is in the middle-line of the abdomen or perineum. But when elicited from the lower limb or the flank, the ipsilateral abdominal muscles and limb flexors react more vigorously than do those of the other side, and indeed their contraction may form the whole response.

A modification in the form of the flexion reflex can sometimes be obtained when the stimulated points in the receptive field are not separated by a great distance. In No. 1 excitation of the outer edge of the planta evoked eversion, with dorsiflexion of the foot, while inversion was more prominent when the seat of stimulation was the outer edge of the sole.

This variation in the resulting movement according to the situation of the stimulus has been called by Sherrington the "local sign" of a reflex. It is well marked in many of the type-reflexes of spinal animals, and its presence denotes a high degree of control over reflexes at this level. In spinal man, the "mass-reflex" is the characteristic feature, and "local sign" is evident to a minimal degree only, indicating that lower mechanisms—e.g., protective reflex—have been set free from control.

(*b*) *Influence of the Condition of the Intra-medullary Part of the Reflex Arc.*

Spinal shock.—Marshall Hall [28] defined the phenomenon of "shock" as the disappearance for a short time of the diastolic actions of the extremities of the frog whose spinal marrow had been severed behind the occiput. To Sherrington ([33] p. 240) it is "the whole of that depression or suppression of nervous function which ensues forthwith upon a mechanical injury of some part of the nervous system, and is of temporary nature." Among laboratory animals it increases as we ascend the evolutionary scale. In man it is more intense than in the monkey. It takes effect in the aboral direction only, and in diminishing degree towards the caudal end of the cord. Reflexes, in man and in animals, are depressed by spinal shock unequally, and this seems to be due to at least three factors.

(1) The degree of dependence of reflex arcs on headward centres. The earliest reflexes to return, if they are ever abolished, when the spinal cord has been divided in man, are reflex contraction of the external sphincters of the bladder and rectum. Retention of urine and

fæces is a constant early feature of all cases of injury to the spinal cord. The shortest interval after the wound at which I examined the conditions of the sphincters was four days, and they were found to be tonic. The sphincter ani contracted in response to pin-pricks applied to the skin round the anus, and there was considerable resistance offered to the passage of a catheter by the external sphincter of the bladder. It is doubtful whether the internal sphincters are in a state of tone at this time. The influence exerted on the spinal reflex arcs of the external sphincters of the bladder and rectum by volition is one of reinforcement, of relaxation on the one hand, and of contraction on the other. The postural pre-spinal centres in the pons and bulb probably help to regulate the postural tone of the muscles. But it is evident that the spinal reflex arcs are efficient to maintain in the sphincters a fair degree of tonic contraction. The detrusors of the bladder and rectum do not recover their reflex activity till later. Automatic micturition begins as a rule three to four weeks after the cord has been divided; but by opening the sphincters with a catheter it can be shown that the bladder-wall reacts effectively to an adequate fluid content considerably earlier than this ([21] p. 190).

In the dog, the reflex arcs of the extensor muscles of the hind limbs are depressed more by spinal shock than are those of the flexors. In the monkey the difference is yet greater, and it is still more in man. The average time, that elapsed before the flexion reflex appeared in the cases of complete cord transection recorded in this paper, was thirteen days, while the knee-jerks could not be obtained till about the thirty-second day.

The flexor neuro-muscular mechanism is spinal in the dog, monkey and man, and is independent of higher control for its purely protective reflex activities. It is thus comparatively slightly depressed by spinal transection, and soon manifests a high state of excitability. But the prime function of the extensor system is the maintenance of posture, for which it depends on the integrity of proprio-spinal paths, the controlling centres being pre-spinal. It would seem that the increasing degree of depression of postural activity from "spinal shock" as the animal scale is ascended from dog to monkey and from monkey to man, indicates a progressive pre-spinal dominance in the series, and that it bears a close relation with the assumption of the upright position.

(2) The "shock" effect diminishes towards the distal end of the cord, so that the reflex arcs of the caudal segments may be but slightly depressed.

One of the earliest reflex reactions to appear is a downward movement and adduction of the hallux in response to a scratch applied to the sole of the foot. In No. 3 it could be evoked at least as early as the seventh day. Occurring at first as an isolated reflex, it is soon accompanied by contraction of the inner hamstring muscles. Later it forms part of a response which consists of flexion at hip and knee, adduction of the thigh, and dorsiflexion at the ankle. Finally, the toe-movement gradually changes in direction from "flexion" to "extension," and the typical flexion reflex with an up-going toe is then the only response evoked by nocuous stimulation of the sole. Holmes [22] has described this early isolated down-going toe-movement as "a unisegmental reflex." The centres of the reflex arcs, in virtue of their situation in the first sacral segment near the caudal extremity of the cord, have escaped the temporary suppression of function which follows spinal transection in centres nearer to the lesion. But the history of the reflex, which is so like the normal plantar response, suggests that its preservation may have a wider meaning. At first the adduction and down-going movement of the toes occurs alone, but as the functional activity of the other reflex arcs of the lower extremity recovers, it becomes gradually submerged in the flexor spasm, the predominant reflex reaction in the lower limbs of spinal man.

A downward movement of the toes forms part of the general extension of the limb in the first phase of step, and it is by far the most common toe-movement employed by the normal individual. It is also the characteristic response to a light scratch or a prick applied to the skin of the sole, and since, with the nervous system intact, inhibition is at its highest, it forms the only movement of the limb. When, however, the affective stimulus is intense and is applied without warning, and especially if the individual is over sensitive to pain, a withdrawal movement of the whole limb may ensue, and brief downward movement of the toes is followed by upward movement. That is to say, inhibition has been broken through for the moment by the sudden application of a harmful stimulus, and a protective reflex, analogous to that at the spinal level, is evoked as the end-effect.

Compare this reaction with that which occurs when the reflex arcs of the lower extremities are separated from cortical control by an injury to the spinal cord, and at a time when reflex excitability in the portion distal to the lesion has returned. A stimulus just liminal can no longer excite a response limited to the toes. Contraction of all the flexors of the limb together with upward movement of the toes, invariably occurs

and, when the spinal transection is complete the flexion reflex can be studied in all its extravagance. "Local signature" has been destroyed. The unit protective reaction of a central nervous system, which is entirely spinal, involves the whole limb, and is never confined to a part of the limb.

The reflex functions of the isolated spinal cord do not become evident, however, till the effects of shock following transection have begun to pass off, and during that time a nociceptive reflex similar to that obtained as a minimal response in the normal individual can be evoked. It is, I believe, the final manifestation of the reflex habits of the complete nervous system when excited by affective stimulation of the sole, and it is preserved for the period of spinal shock because its reflex centre is situated in the caudal extremity of the cord, thus escaping complete suppression of function. Later, when the functional activity of the isolated portion asserts itself, this remaining representation of higher neural control becomes submerged in and finally destroyed by the protective reflex of the spinal level. The external sphincters of the bladder and rectum seem to retain some tonicity and reflex contractility even from the first.

(3) Reflexes originated by stimuli which in the intact individual have a strong affective quality suffer relatively slightly from spinal shock.

Sherrington ([33] p. 231) has observed that protective or "nociceptive" reflexes are least depressed by spinal transection, and are prepotent in that they "prevail over reflexes of other species when in competition with them for the use of the 'final common path.'" Walshe [42] believed that a minimal flexion response is the only "skin-reflex" preserved in cases of complete transverse lesion of the cord.

I have found that, besides the flexion reflex of the lower extremity, those reflexes which belong to the generative system and which have, in consequence, in the intact individual a strong affective tone, emerge early from shock. Cremasteric, dartos and bulbo-cavernosus reflexes were obtained in each patient, except No. 4, on the day of his admission to the Empire Hospital, so that in all probability they were obtainable at an earlier date. In No. 1 they were elicited on the eleventh day after the injury and before any sign of reflex activity was evident in the lower extremities, and in No. 3 on the seventh day. Adequate stimuli were rubbing or scratching the skin round the penis and scrotum or pricking the glans penis. At this time, erection of the penis could not be evoked and the threshold value of the stimulus was high; but later by gently rubbing the penis and especially by moving the prepuce backwards and

forwards over the glans the complete "coitus reflex" could be excited with ease.

The various theories put forward by physiologists to explain the phenomena of shock need not be enumerated here. But it is important to remember that Sherrington ([33] p. 246) believes that the block in the reflex paths occurs at the termination in the cord of the *afferent* channel and that "the much severer character of the depression when the transection passes behind the pons indicates an aborally directing influence from some nucleus of the pontine or mid-brain system, driven probably by the great cranial receptors of the otic labyrinth and eye, reinforced by influences from the cord itself."

Toxic states.—The general health of the patient has a great influence on reflex excitability by reacting on the functional condition of the spinal centres. Should the blood be poisoned from the first by septic absorption, the isolated segments may pass into the state of "isolation alteration" before the period of spinal shock is over. The paralysed muscles waste rapidly, and apart from a tonic condition of the rectal and vesical sphincters, cremasteric and bulbo-cavernosus reflexes and a minimal flexion reflex in response to nocuous stimulation of the sole, reflex activity is in abeyance.

When the toxæmia develops in the second stage of reflex excitability, as so frequently happens from urinary sepsis, depression of the reflex functions of the cord is sometimes preceded by a short initial period of exaltation. Then, as the pyrexia goes on, the lower extremities and the abdominal wall fall into spasm less frequently and vigorously, the threshold value of stimuli is raised, receptive fields narrow, a massive response is more difficult to evoke, the bladder evacuates its contents less regularly and perfectly, and sweating occurs from the whole body surface. The reflex arcs of the extensor muscular system are more vulnerable than are those of the flexor system. Thus while flexor spasms of the lower extremities are still easy to evoke, the knee- and ankle-jerks are sluggish and uncertain. Tone in the quadriceps cruris and calf muscles suffers relatively more than in the hamstring and pretibial muscles. If the toxic febrile attack is not of long duration, the paralysed parts may almost completely recover their former activity and the muscular wasting may disappear.

It is well known to physiologists that various drugs, including chloroform, have a deleterious influence on the reflex functions of a severed cord. General anæsthetics have undoubtedly the same effect in man, and for some time after a prolonged operation the reflexes are more difficult to elicit.

General fatigue is another powerful depressant of reflex activity, but its effects are usually of more temporary nature than are those of toxic poisoning from sepsis or of chloroform. Like spinal shock they all affect those segments which lie nearest to the lesion, more than those more caudally placed.

Local fatigue may be induced by repeated excitation of reflex arcs. A spinal reflex in animals under continuous stimulation of one part of the receptive field becomes gradually weaker and more tremulous and ultimately may disappear altogether. When the reflex under observation is flexion of the hind-limb, it has been shown by Sherrington ([33] p. 214) that it is not the flexor muscles themselves which tire out; for though they respond no longer to appropriate stimulation of the planta, they still contract in response to the scratch-reflex. When a reflex can no longer be obtained from one spot in consequence of fatigue it may be easily evoked from another spot; this second spot need not be at any considerable distance from the first. Local fatigue as observed in the cases recorded in this paper is thus similar in its manifestations to those described by Sherrington in the spinal dog. A flexion reflex of the lower extremity tired out by repeated stimulation of a spot in the receptive field can be immediately obtained from another spot a short distance away from the one previously excited. Some reflexes can be fatigued sooner than others. The knee- and ankle-jerks, for example, decline earlier than do the hamstring jerks. The effects of local fatigue on spinal reflexes are remarkably shortlived, and it would seem that weak stimuli are just as potent to produce depression as are those of greater intensity.

Its local character, as Sherrington has shown, does not necessarily imply that the fatigue is manifest in the receptor organs of the skin, though undoubtedly its expression is on the afferent side of the arc. The ease with which the same "common paths" are excited by stimulation of different parts of the receptive surface for the reflex proves this beyond doubt. Sherrington concludes that the seat of fatigue is intraspinal and that it affects the afferent part of the arc probably at the first synapse. "It seems a process elaborated and preserved in the selective evolution of the neural machinery. One obvious use attaching to it is the prevention of the too prolonged continuous use of a 'common path' by any one receptor. It precludes one receptor from occupying for long periods an effector organ to the exclusion of all other receptors. It prevents long continuous possession of a common path by any one reflex of considerable intensity. It

favours the receptors taking turn about; it helps to ensure serial variety of reaction. The organism in a million-sided environment must, in its reactions, be many sided. Were it not for such so-called 'fatigue' an organism might, in regard to its receptivity, develop an eye, or an ear, or a mouth, or a hand or a leg, but it would hardly develop the marvellous congeries of all those various sense-organs which it is actually found to possess" ([33] p. 322).

(c) *Inhibition and Facilitation.*

We have seen that the nature of a reflex response is dependent on certain conditions attaching to the exciting stimulus and to the intramedullary path of the reflex arc. We have now to consider briefly how all other portions of the nervous system, with which the reflex arc is still in communication, influence it.

A vertebrate animal, such as the dog, reacts as a whole to the environment and in virtue of this the entire nervous system is linked up by means of neuronic intercommunications, so that no segment can react entirely on its own. In man, the integration of the nervous system, and so of the whole body, has reached a high degree of perfection with dominance of his surroundings. This has been achieved by more complex interconnections between all reflex arcs. All movements that serve any useful purpose can only be effected by the co-operation of a number of muscles, some contracting to bring about the movement and others relaxing to allow the movement to occur. The whole is a perfectly co-ordinated reaction showing a fine adjustment to requirements, so that impulses originating from a stimulus alter the state not of one muscle but of many muscles, the number involved and the vigour of the movement depending on necessity.

The decerebrate dog, which may be considered a complete reflex entity, reacts as a whole to a stimulus. The perfect posture of standing can be maintained by the mutilated animal for hours on end; and a response to irritation, closely similar to that of the intact animal, is obtained. Goltz has described its reaction to a stimulus which, under normal conditions, would have pain as its conscious correlate. When a toe is severely pinched, the foot is drawn up out of harm's way and the animal makes locomotory movements with the other three legs, at the same time turning its head round and showing its teeth.

The view was expressed on p. 338 that the reflex behaviour of the lower extremities of such a case of partial damage to the cord as No. 6 resembles that exhibited by the decerebrate dog. When at rest they

lie extended on the bed and the active extension of the limb which follows pressure on the sole of the foot is comparable with the first phase of step and with the extensor thrust of Sherrington. The application of a prick to the foot is followed by flexion of the limb, a reflex withdrawal of the part from harm, and by an active thrust of the crossed limb, a movement strictly analogous to that evoked in the decerebrate animal.

Such a case exhibits postural tonus comparable with decerebrate rigidity and it is believed that, in virtue of the preservation of reflex arcs on which posture depends, the reflex activities of the lower extremities are controlled and combined together in harmonious unity. Impulses entering the cord excite motor discharges which in the form they take show a degree of adaptation to the locality and quality of the stimulus, not observed when the conduction of the cord has been completely destroyed. Flexion of the lower extremity can be obtained not only as a protective reflex reaction but also a phase in the steppage movements of the limbs.

In No. 6, by pressing on the balls of the toes, the lower limb resting in a position of flexion, an active extension movement of the whole limb was evoked and was sometimes followed by flexion and then again by extension of the limb. The crossed lower extremity as a rule took part in these movements of progression, but in opposite phase to the other.

The involuntary movements of the feet observed in this patient were invariably bilateral, and dorsiflexion of one foot was always accompanied by plantar-extension of the other.

It was found that inhibition of wide irradiation of impulses in the cord was associated with the presence of postural activity. Thus, though the reflex functions of the bladder in No. 6 had reached a high state of efficiency, the quantity of fluid, which formed the adequate endovesical stimulus, could not be diminished by stimulation of the sole of the foot or by deep breathing. Conversely movements of the lower extremities never accompanied the act of reflex micturition or defæcation. From the presence of "local signature" or inhibition, impulses originated by a stimulus, somatic or visceral, excited only those motor paths which corresponded with afferents along which they had travelled to the cord. Somatic stimulation could not facilitate a visceral reflex nor could endovesical stimulation provoke somatic reactions.

When, however, the spinal reflex arcs are completely shut off from the influences of headward centres, as by spinal transection, postural activity is abolished and a lowly form of inhibition is alone evident. It

is practically confined to short spinal reflexes. In the nociceptive reflex of the lower extremity, contraction of the flexors is always accompanied by inhibition of the extensors. So also in the reflex reaction of the bladder or the rectum, relaxation of the sphincter occurs simultaneous with contraction of the detrusor. But apart from the reciprocal innervation of antagonistic muscles, inhibition is little evident. The influence exerted on the reflex actions of one part by all other portions of the isolated cord is of such a character that they are augmented rather than inhibited. Impulses entering the cord overflow and excite with great ease reflex arcs other than those under stimulation, so that a single stimulus evokes a wide compound reflex reaction. A unilateral flexor spasm of the lower extremity or of the abdominal wall may follow weak nocuous stimulation of the skin of the foot or of the abdomen, but a stimulus of moderate intensity will provoke a bilateral flexor spasm of the abdomen and lower limbs. Impulses irradiate to and excite motor neurons not only of the voluntary but also of the involuntary nervous system and vice versa. Flexor spasms may accompany the act of micturition, and, by stimulating any part of the receptive field for the flexion reflex, evacuation of the bladder can be induced when it contains but half the quantity of fluid with which it reacts alone.

The complete mass-reflex, consisting of a bilateral flexor spasm of the ventral abdominal wall and of the lower extremities, evacuation of urine and hyperidrosis, is produced by the simultaneous combination of allied reflexes. It is an extravagant reaction to a harmful stimulus, and is excited by wide irradiation of impulses in the cord. In all cases of spinal injury in which this extensive motor discharge can be evoked, postural activity is abolished and flexion of the lower extremity can be obtained as a protective reflex only. Primary extension reflexes are absent and diphasic movements of flexion and extension of the lower limbs, resembling those of locomotion, are never observed.

To sum up, the phenomenon of inhibition of reflex spread occurs in those cases of spinal injury which exhibit postural activities. The presence of postural tonus in the extensor muscles of the lower extremities indicates that intraspinal paths, which connect the reflex centres of the lumbar enlargement with the whole spinal cord and with prespinal centres in the pons and mid-brain, are not destroyed by the lesion. The influence then exerted on a reflex arc by portions of the nervous system with which it is still connected is one of inhibition or control.

In cases where these paths are cut off, inhibition is almost completely absent except in so far as it applies to reciprocal innervation of antagonistic muscles; and postural tonus in the muscles of the lower limbs is abolished. On the other hand, the mass-reflex is the result of great facility of spatial spread of impulses from a point of entry in the cord. The parts of the spinal cord with which a reflex arc is still in communication facilitate and augment its activities.

(2) Muscular Tonus.

During the stage of muscular flaccidity the paralysed muscles are toneless. With recovery of the reflex functions of the isolated portion of the spinal cord the muscles become less flabby and offer some resistance to pressure with the finger. In the lower extremities the reflex arcs which control the flexor muscles regain their excitability before those which control the extensor muscles. When the spinal cord has been completely divided, the flexor muscles throughout, in both the resting and the contracting state, show more tone than do their antagonists, but the tone of all the paralysed muscles when resting is below normal. The extensor muscles are more hypotonic than are the flexors. On the other hand, in such a case as No. 6 no obvious difference in tone in the two-muscle groups can be demonstrated. Moreover, they may be and usually are hypertonic. When not in contraction their tone is appreciably greater than the tone of the muscles of the lower limbs of a patient whose cord has been completely divided.

Botazzi's theory of the "functional duality" of muscle is likely to be of the greatest importance to clinical medicine. Farquhar Buzzard [12] a few years ago applied it to the elucidation of such conditions as congenital myotonia and myoclonus. He suggested that the prolonged tonic muscular contraction of the former is due to excessive sarcoplasmic activity, and the involuntary movements of lightning rapidity so characteristic of myoclonus to exaltation of fibrillary excitability.

In a recent paper "On Muscle Tonus" [23] Langelaan expresses the view that a tonic muscle is continually in a state of slight contraction, combined with a state of exalted plasticity. This condition is maintained by the ceaseless weak excitation of the proprioceptors of the whole apparatus of locomotion brought about by movements of the body. He believes with Boeke that plasticity is the chief property of the sarcoplasmic part of the muscle and is innervated by a sympathetic

nerve fibre analogously to smooth muscle; and that the contraction factor is due to the sarcostylic element of the muscle which is under the control of the motor cell of the anterior horn. He designates the two components of muscle tonus as "plastic or automatic tonus" and "contractile tonus." The receptors of the proprioceptive reflex arc are situated in the muscles, the tendons, the fasciæ, the joints and the periosteum, and the adequate stimuli for exciting them are extension of the muscle and tendon and stretching of the fasciæ, movements in the joints, &c. The afferent fibre from each receptor enters the cord along a posterior root and splits up into collaterals which terminate round the cell of a skeletal motor neuron, and a large motor cell whose axon leaves the cord along the anterior root and passes over into the sympathetic chain by way of the white ramus communicans.

He concludes from the results of his experiments "that the impulses set up in the afferent part of a proprioceptive reflex arc by stimulating the proprioceptors of a muscle not only go over upon the efferent part of its own proprioceptive reflex arc, but also upon the efferent part of those reflex arcs which belong to muscles antagonistic to the stimulated one. The way of least resistance for the passage of the stimulus to the efferent part of an antogonistic reflex arc leads to the sympathetic motor cell." He considers that the interaction of antagonistic muscles in the production of co-ordinated movements is based on this principle.

He agrees with Sherrington that the tendon phenomena are true reflexes and that they are typical manifestations of the proprioceptive reflex arc. From examination of the myogram of the knee-jerk, he shows that it is of twofold nature—a twitch upon which is superposed a tonic contraction. The components he considers to be independent of each other, and he quotes de Boer's experiment on cats in support of his view. When the rami communicantes of the sympathetic chain were cut, tonic contraction which represents "plastic tonus" in the knee-jerk was destroyed, but the twitch could still be obtained and was even brisk. Again, "contractile tonus" may, be believes, be affected while "plastic tonus" remains perfect.

Now my observations on the character of the knee-jerks evoked in cases of complete anatomical transection of spinal cord showed that it consisted simply of a twitch; when the patellar tendon was sharply tapped, with the knee supported in a slightly bent position so as to put the quadriceps cruris muscle on the stretch, the leg extended briskly on the thigh and as quickly fell on the bed again like a dead weight. By watching the tendon it could be seen to tighten suddenly and then

to relax immediately. The knee-jerk of No. 6, and of those who belonged to the same group, was of different character. The twitch of the response was just as brisk, but the leg fell away more slowly and the relaxation of the tendon was more deliberate.

It seems to me that while in both cases the contractile element of tonus was present and produced the twitch, the plastic element was absent in the former and present in the latter, causing after-prolongation of the contraction. In all patients like No. 6, in whom primary extension reflexes could be evoked, tonic after-contraction in the knee-jerk could be detected.

Langelaan is of opinion that "decerebrate rigidity" is "plastic tonus," being due, in part at least, to a spasm of the sarcoplasmic element of the muscles involved. To Sherrington it is reflex standing or postural contraction and is the expression of exalted reflex tonus. He has shown [37] in the dog that reflex tonus in the musculature of the lower limbs of the decerebrate preparation is distributed to those muscles which are in active contraction in the extensor phase of step and to no others. It is a proprioceptive reaction of anti-gravity muscles, and the impulses which excite and maintain it originate in the receptors of the muscles themselves, their tendons, fascial sheaths, &c. The adequate stimulus is mechanical stress or tension of these tissues. It is destroyed by section of the posterior roots.

Sherrington has proved that the reflex system, which subserves postural contraction, is composed of reflex arcs at two levels, spinal and prespinal. The prespinal centres are situated chiefly in the pons, bulb, and mid-brain, and their activities are adjusted and supported by impressions from the labyrinths and the cerebellum. The dog when made spinal can often stand for short periods after the depression of spinal function has passed off, but the hind-quarters are apt to collapse at any time. The spinal monkey is unable to stand at all, and in man, when the spinal cord has been transected, postural activities are entirely absent.

It would seem then that as the vertebrate scale is ascended, or, as one might express it, as the functions of upright standing and upright walking are taken over more completely by the hind-limbs, the prespinal centres of the postural neural mechanism dominate more and more those at the spinal level. In man, as regards skeletal muscles, they have supreme functional control, and when the spinal cord is cut across, "reflex tonus" (Sherrington) or "plastic tonus" (Langelaan) seems to disappear from the extensor muscles of the lower limbs. For not only

is tonic after-contraction in the patellar tendon response apparently absent, so far as clinical observation can tell, but the other signs of postural activity, e.g., the extensor thrust, homolateral and bilateral extension of the lower extremities, cannot be evoked by appropriate stimulation.

Since the automatic functions of the bladder and rectum recover so perfectly that practically all the contents of these organs are expelled by each reflex act, it is probable that the tonic reflex arcs for visceral muscles remain spinal. The mechanism subserving tonus in detrusor muscles such as those of the bladder may be even more peripherally placed as the recovery of bladder functions following lesions of the cauda equina would seem to indicate [21].

(3) Reflexes as Adapted Reactions.

I have attempted to show how the form of a reflex movement in spinal man is modified by the character and locus of the exciting stimulus, by the condition of the central part of the reflex arc and of the associated portions of the spinal cord. On stimulation of peripheral sense-organs, whether extero-ceptors, proprio-ceptors, or intero-ceptors, the reflex evoked is represented by a true co-ordinated motor act in which not only do many muscles take part, but there is perfect harmony between the strength, duration and time of contraction of each muscle, that participates in the action, and of relaxation of each antagonistic muscle. The movement, in that it shows adaptation to the quality and locality of the excitant, is purposeful, and is an attainment of a useful effect. One can attribute "purpose" to three groups of reflexes in spinal man, namely, protective, sexual, and excretory.

Grainger in 1837 [20], Goltz [17], Sherrington ([33] p. 239) and many other investigators have pointed out that reflex spinal movements excited by affective cutaneous stimuli are often defensive in character. If the leg of the spinal frog is pinched it is drawn away as though to escape from the harmful irritant. The application of a drop of dilute acid to the flank of the animal evokes a series of movements which are apparently directed to the purpose of removing the obnoxious stimulus. Withdrawal movements of the hind-limbs of the spinal dog immediately follow hurtful excitation of the foot, and the "scratch-reflex" (Sherrington) is a perfectly co-ordinated and rhythmic action of flexion and extension of the limb adapted to remove the source of irritation. Defensive reactions are likewise exhibited by the spinal monkey.

When the spinal cord has been completely divided in man, the only

movements evoked by stimulating the lower extremities to which, in my opinion, a useful effect can be attributed, are the flexor spasms and the flexion reflex. I entirely agree with Sherrington and Walshe in assigning to these reflexes a protective function. In the musculature involved, in the central focal area of the receptive field for the reflex and in the quality of the adequate stimulus they are closely analogous to the defensive reactions described by physiologists in spinal animals. Marie and Foix [26 and 27] maintain that they resemble more the steppage movements of the spinal dog. But surely their belief is ill-founded on the experimental facts. Movements of progression, obtained also in some cases of less gross damage to the spinal cord in man, have extension of the stimulated limb with flexion of the other as the primary phase and are evoked by a stimulus devoid of affective tone, namely, gentle pressure on the sole of the foot, which is strictly analogous to the normal pressure stimulus of the ground in walking. Further, after the reflex has been initiated, alternating movements of the lower limbs continue as a rule for some time. I have failed in any case of cord transection to excite such locomotory movements. In man the control of postural function in the lower extremities seems to be entirely relegated to prespinal centres, and with severance of the cord "plastic" tonus in the extensor muscles disappears. It is true that from the presence of contractile tonus in the quadriceps cruris and calf muscles, due to intact spinal reflex arcs, knee- and ankle-jerks can be evoked by independent stimuli; but both muscle groups cannot be excited by a single stimulus to react as a functional unit and to perform a movement useful to the limb as a whole. With postural tonus in the extensor muscles, one limb can no longer move without some change in the opposite direction taking place in the other. In their reflex actions they are combined and unified whether for protection or for locomotion. But in spinal man the primary function of the lower limbs ceases to be postural and locomotory, and the lowly reflex system which subserves merely the preservation of the parts from harm is set free from control. Its activities now emerge and swamp the clinical picture. A governor is no longer placed upon them and their excessive and violent character become the terror and despair of the sufferer.

As has been seen, the amplitude of the flexor spasm and the extent of the muscular field involved is influenced to a certain extent by the intensity of the affective stimulus. A single prick applied to the sole may result in a withdrawal movement confined to the irritated limb.

But impulses spread with ease in the isolated spinal cord, and in response to a more harmful stimulus a wild extravagant reaction of defence is elicited. The spasm involves both lower extremities and the abdominal wall, urine is voided, and the patient sweats profusely. So completely has resistance to nocuous impulses been destroyed with section of the cord, that an excessive reaction to pain can be evoked reflexly by a pinch or a scratch.

The receptive field of protective reflexes has usurped the whole surface of the paralysed region of the body by invading the reflexogenous area for postural reflexes. Always prepotent, they now completely dominate the activities of the spinal centres. The crossed extension reflex in No. 1 was immediately replaced by a flexor spasm of the limb when any part of the leg was pinched or pricked. In six of my eight cases of spinal transection the crossed response to a flexion-reflex was invariably a flexor spasm.

Besides these defensive acts there are co-ordinated reflexes in spinal man, as in spinal animals, connected with the reproductive functions. According to Goltz and other observers, ten days after the operation of spinal transection in the thoracic region of the dog, when the effects of shock have quieted down, sexual reflexes can be evoked. "If the penis is excited by masturbatory manipulations the phenomena of erection and seminal ejaculation follow, associated with movements or postures of the hind-limbs that express voluptuous sensations" [25]. In the female the reflex cannot be elicited by touching analogous parts, as would be expected, if the interpretation of its "purpose" was correct, from the different rôle which she plays in the sexual act.

The reflex response which I have called the "coitus reflex" is evoked from the penis and consists of a complex act whose purpose is undoubtedly sexual. When the penis is lightly grasped, as in washing the organ preparatory to passing a catheter, and the prepuce is drawn backwards over the glans, the penis slowly stiffens and becomes firmly erected. With this reaction the testicles are drawn up a little, the scrotum wrinkles, the muscles of the ventral abdominal wall contract sharply, and both lower extremities may flex. This flexion may be somewhat delayed. The patient remains completely unconscious of any of these manipulations.

The reflex can be obtained with equal ease when the cord has been less severely injured and postural activity is present in the lower extremities. It then differs in one important respect from that above described. In spinal man the reflex component in the lower limbs is a

bilateral flexor spasm, a movement which would tend to nullify the adequacy of the reflex act in its end-effect. In No. 6, however, the legs assumed a posture of rigid extension in the primary phase, making the composite movement perfect in its purpose. In spinal man, the ease with which impulses spread in the cord and excite the motor paths of the flexors interferes with the adaptation of the act as a reflex. In the other group, the presence of postural activity in the extensors makes the reflex perfect as a phasic purposive movement leading up to a definite result.

The third group of reflexes to whose activities purpose can be attributed is that concerned with excretion. The automatic functions of the bladder and rectum recover from "shock" earlier in animals than in man, and the walls of the viscera, at all events in the dog and cat, are less liable to septic infection. We have seen how perfect the adaptation to end becomes, under favourable conditions, in the activities of the neuro-muscular mechanism of the bladder. At first, as the spinal centres begin to throw off the depression of shock, urine is voided at irregular intervals and in small and unequal quantities. But gradually the functional activity of the reflex arcs is regained, and soon the amount of fluid forming an adequate endo-vesical stimulus becomes more or less constant, and each act of evacuation is complete. A bladder which is excited by the tension exerted by 300 c.c. of urine will continue to react to approximately that content provided toxic complications do not appear. In the reflex act motor discharges are released which lead to contraction of the bladder-wall, and with this other alterations in the central organ take place which bring about simultaneous relaxation of the sphincters, giving the urine a free passage into the urethra. Often the last few drops can be observed to be expelled with a spurt, the urethral muscle completing the evacuation. The bladder with its spinal reflex mechanism is, at this stage, performing its functions of excretion in a manner approaching in perfection that attained with the nervous system intact.

Automatic activity of the rectum returns *pari passu* with that of the bladder, and so long as the contents of the bowel are soft or of slightly loose consistence they will, as a rule, be voided without help. No. 1 rarely required enemata, and even mild aperients were unnecessary when his general health was good. To find out experimentally the tension of the rectal wall necessary to evoke a reflex act is more difficult than with the bladder, but as a rule a content of 6 to 8 oz. (170 to 230 c.c.) of fluid form the adequate stimulus. In my experience passive dribbling of urine

or fæces is unknown, except just before death robs the spinal reflex arcs of their vigour.

In man, integration of the nervous system has reached the highest development yet attained in the animal kingdom, and in him "the great projecting senses of the cranial region" [33] dominate the spinal cord more than in animals; but the spinal reflex mechanism of the elementary functions of protection, reproduction and excretion, which are the oldest in the phylogenetic scale, still retain some power of autonomous action, though it is less complete than in the monkey, and still less than in the dog.

Chapter VI.—Conclusions.

Total Transverse Lesions.

(1) A study of several examples of complete division of the spinal cord due to wounds of war has shown that the clinical picture hitherto described as typical is imperfect. Under favourable conditions the portion of the spinal cord caudal to the lesion not only recovers its reflex functions, but becomes highly excitable.

(2) Three clinical stages may be recognized: (*A*) The stage of muscular flaccidity; (*B*) the stage of reflex activity; (*C*) the stage of gradual failure of the reflex functions of the isolated portion of the cord

(A) First Stage.—

(3) The first stage of muscular flaccidity corresponds with the period of deep depression from "spinal shock." It may be said to come to an end either when the first reflex response to an external stimulus applied to the abdominal wall or lower extremities can be evoked, or when involuntary movements of these parts make their appearance.

(4) In this first stage the paralysed skeletal muscles are toneless and flabby; superficial and tendon reflexes are absent, but at times cremasteric and bulbo-cavernosus reflexes may be elicited. There is complete anæsthesia and analgesia below the level corresponding to the lesion. The skin is dry and readily becomes gangrenous. There is retention of urine and of fæces. In three patients this stage lasted from one to three weeks.

(B) Second Stage.—

(5) In the second stage of reflex activity, reflexes, many of them complicated and showing adaptation to an end, can be evoked from almost any part of the paralysed region of the trunk, extremities and viscera.

(6) The first reflex which appears is most often a response to nocuous stimulation of the sole of the foot. Three different forms of this reflex have been observed: (*a*) adduction and flexion of the toes; (*b*) adduction and flexion of the toes together with a tightening of the inner hamstring tendons; and (*c*) upgoing toes with contraction of the inner hamstring muscles.

(7) In the full development of this stage, a nocuous stimulus applied to the sole, or to any part of the lower extremity, either to the superficial or deep tissues, gives rise to a flexion reflex consisting of flexion at the hip with adduction of the thigh, flexion at the knee, dorsiflexion at the ankle, and upgoing toes. In all patients, during this stage, when reflex contractions occur in one physiological group of muscles simultaneous inhibition of their antagonists can be demonstrated.

(8) With a flexion reflex of moderate strength a reflex in the opposite limb is obtained as a rule. In six out of the eight cases this was flexion. In the other two cases it consisted of a slight contraction of the quadriceps cruris and sometimes of the calf muscles but was of insufficient power to extend the limb. Moreover in neither of these cases was it constant; at one time it might be evident and palpable and at another a vigorous flexor spasm would be the crossed component.

(9) In this stage of reflex activity, provided that the level of the lesion is sufficiently high to cause paralysis of the abdominal wall, the ventral abdominal muscles are readily excited by nocuous stimuli. By scratching the skin of the flank a local contraction of the external oblique muscle is obtained, which follows the course of the muscle fibres, i.e., upwards and outwards from the sheath of the rectus towards the costal margin. In the early portion of this stage a similar stimulus applied to the skin over the rectus may evoke a response confined to this muscle, which, though most pronounced under the stimulated point, involves the length of the muscle as a whole. Stronger excitation produces a general contraction of the ventral abdominal wall, so that the patient is pulled forwards. A still stronger stimulus is followed by a flexor spasm of the ventral abdominal wall and of the lower extremities. The receptive field for this widespread reflex comprises the superficial and deep structures of the abdomen and lower extremities.

(10) When reflexes can be evoked with ease, an excessive and widespread reflex reaction can be obtained. This reaction has been called a "mass-reflex." By scratching any part of the lower limbs or of the ventral abdominal wall, if it be paralysed, a complicated response may be obtained, of which the following are components:—

(*a*) A flexor spasm of the ventral abdominal wall and of the lower extremities.

(*b*) Evacuation of the bladder when its contents are scarcely half the amount at which it otherwise would empty itself.

(*c*) Sweating from an area of skin varying with the level of the spinal lesion.

(11) During this stage of reflex activity one of the most receptive fields for exciting reflexes is the genital area. In its full development the reflex from the genital area involves the musculature of the genital organs, of the ventral abdominal wall, and of the lower limbs. The components of this reflex are in order of their appearance: (*a*) Cremasteric and dartos reflexes: these are evoked by movements of the prepuce over the glans, by handling the scrotum, by scratching the inner portions of the surfaces of the thighs and of the perineum. (*b*) Bulbo-cavernosus reflex which is excited by gently irritating the glans through the prepuce or by pricking the glans penis. (*c*) Erection of the penis and seminal emission.

(12) By sharply tapping the patellar tendon, and the tendo Achillis, knee- and ankle-jerks can be evoked. The earliest date for the appearance of the extensor tendon jerks was the twenty-first day and the latest the fifty-third day after the injury, i.e., one to five weeks later than the date of the appearance of the flexion reflex. At first the response consisted of a tightening of the slack tendon with no movement at the knee or ankle-joint, but later active extension of the leg or foot resulted from appropriate stimulation. The knee- and ankle-jerks could be inhibited by inducing simultaneously a flexion reflex in the same lower limb. A well-sustained ankle clonus was never obtained, but at times a few clonic jerks unequal in amplitude and irregular in time could be observed.

(13) During this stage of reflex activity, under favourable conditions, the contents of the bladder and rectum are voided automatically. On an average automatic micturition and automatic defæcation occurred for the first time in the third week. But before the "clinical stage of retention" had come to an end, it was proved by experiment that the detrusor muscle of the bladder was acting reflexly to an adequate stimulus, though this action was not of sufficient strength to overcome the tonic activity of the sphincters. It is evident therefore that a distinction must be made between automatic evacuation through a catheter and automatic micturition.

With a catheter in place, the automatic evacuation can be measured

under experimental conditions. It implies a contraction of the detrusor *without* inhibition of the sphincter. Automatic micturition implies a contraction of the detrusor *with* inhibition of the sphincter.

(14) As soon as the reflex arcs of the bladder and rectum regain their full functional activity, each organ responds to a content which varies in different patients and with certain conditions. For example, a bladder which had never been distended, or subjected to the ravages of septic infection, reacted reflexly as a rule to a larger amount of fluid than did a bladder whose musculature had been stretched by initial distension or by careless manipulation, or had deteriorated owing to repeated attacks of cystitis.

Experimentally the bladder reacted to a content of from 100 c.c. to 650 c.c. As the functional activity of the bladder recovered the residual urine diminished in amount and ultimately all its contents might be discharged completely.

The rectum reacted in a fashion similar to the bladder and the reflex could be initiated by injecting from 56 c.c. to 280 c.c. of fluid, depending upon the quantity of fæcal content at the time.

Passive dribbling of urine and fæces was never observed except in one patient (No. 5) in whom it occurred a few hours before death.

(15) In the stage of reflex activity the vasomotor balance is more stable, when febrile complications are absent, than in the stage of muscular flaccidity. If the legs are let down gradually little or no œdema develops. Venous thrombosis occurred in two out of eight cases. Apart from complications, the skin of the paralysed parts regains a good colour and a normal temperature.

(16) If excessive sweating occurs it generally makes its appearance in this stage of reflex activity. The area of hyperidrosis varies with the level of the spinal injury. The hyperidrosis is due to an excessive activity of the nervous mechanisms arising from the spinal cord below the level of the lesion. Thus with a lesion at the level of the third thoracic segment it occurred over the arms, over the trunk below the second rib and over the lower extremities. When the spinal transection was through the sixth thoracic segment the sweating was confined to the palms, to the trunk below the level of the fifth rib, and to the lower limbs. A lesion at the level of the ninth thoracic segment gave rise to sweating over an area which corresponded to the analgesic portions of the trunk and lower extremities.

When the clinical course of the patient was complicated by febrile conditions, such as pyelitis, sweating occurred over the whole surface

of the body. Similarly, sudorific drugs, such as aspirin, or immersion in a hot bath, evoked sweating over the body as a whole.

(17) During this stage of reflex-activity the skin becomes more healthy, and under treatment it is possible to induce bed-sores to heal. In those patients, however, in whom septicæmic or other toxæmic conditions develop, the resistance of the tissues again falls and remains low so long as the acute phase of the illness lasts.

(*C*) *Third Stage.*

(18) The third stage of gradual failure of the reflex functions of the isolated spinal cord precedes death, and is brought about by toxic febrile complications. Gradually the reflexes become more and more difficult to evoke, the extensor tendon-jerks disappearing first. Irradiation of impulses in the cord is prevented and a mass-reflex response can no longer be obtained. The receptive fields narrow towards their focal areas and the threshold values of the various stimuli become raised. The bladder and rectum now evacuate their contents less perfectly, so that the residuum after each expulsive act increases in amount. The stage of retention of urine and faeces may even return. In one patient passive dribbling of urine preceded death by a few hours. The skin sloughs after slight continued pressure and sweating becomes general while the fever lasts.

Comparison of the Manifestations in complete Division of the Spinal Cord with those found in some less complete Lesions.

(19) There are no manifestations by which we can be certain that the spinal cord has been anatomically divided.

(20) But in some cases, where the spinal cord had been severely damaged and motion and sensation were abolished and the bladder and rectum acted automatically, certain manifestations were present, which did not occur in cases where the spinal cord was proved to have been anatomically divided.

(21) Movements of the flexor type were the only primary motor reactions observed in cases of complete transection of the spinal cord.

(22) In a group of cases, where the spinal cord was less extensively damaged, the involuntary movements may contrast strongly with these primary motor reactions, and may either simulate movements of progression, or be entirely extensor in type. If in this class a flexor movement appears, it has not the uncontrolled character which is so commonly observed when the spinal cord has been completely divided.

The involuntary response in this class of case is a movement and not a spasm.

(23) The presence of this postural mode of response depends upon the integrity of certain descending propriospinal paths, which link up the centres in the cord below with those above the lesion and with controlling centres in the pons and medulla. Should these paths be grossly interfered with, primary extension is no longer possible, although the total damage to the spinal cord may be far from complete.

(24) When the section of the spinal cord is complete in the stage of reflex activity, the posture of the lower limbs in the resting stage is one of slight flexion at the hip and at the knee, slight adduction of the thigh, and dorsiflexion of the foot and toes. In the group of cases of partial lesion, considered in this paper, the lower extremities lie in the bed extended at the hip and at the knee, with the feet and toes pointing slightly.

Whatever the extent of the lesion may be, the patient, by the time the second stage of reflex activity is reached, is usually subjectively aware that he has legs. When the lesion is complete, the limbs may seem to him to be more or less flexed at the knee, whilst in the particular class of incomplete lesions dealt with in this paper the limbs seem to the patient to be extended at the knee.

(25) In certain cases of incomplete injury to the spinal cord, though the motor response obtained by the application of nocuous stimuli to the sole of the foot is invariably a flexion reflex of the lower limb, yet this flexion reflex differs from the "mass-reflex" in many of its characters.

The main points of difference are: (*a*) The flexor movement excited by a stimulus of moderate intensity is less violent. (*b*) The flexion reflex is invariably accompanied by a crossed extension reflex. (*c*) There is frequently active extension of the limb associated with flexion of the contralateral limb following the flexion phase of the reflex in the stimulated lower extremity. (*d*) The abdominal wall is only involved in the motor response with stimuli of intense nociceptive value. (*e*) The receptive field of the flexion reflex does not extend higher than the knee (though the focal area in which the threshold value of the stimulus is lowest, as it is in all cases of spinal injury, is the sole of the foot).

When the spinal cord has been completely divided, the reflex in the ipsilateral lower limb is invariably uniphasic in that only one group of muscles—the flexors—is thrown into contraction. The extension which

follows the contraction is due entirely to a relaxation of the flexor muscles and to gravity.

(26) Two reflexes which are not obtained when the spinal cord has been entirely severed can be evoked in the group of cases of partial injury under consideration: (*a*) Homolateral or bilateral extension of the lower extremities excited by moving the prepuce forward over the erected glans penis, or by nocuous stimulation of the upper parts of the thighs, or of the perineum. (*b*) Active extension of the lower extremities, when the distal portion of the sole of the foot is pressed upwards, the limb having first been passively flexed. This reflex is analogous to the extensor thrust, described by Sherrington as occurring in decerebrate and spinal animals. Extension is frequently followed by flexion, and may start steppage movements in the two lower limbs.

(27) The knee-jerk differs in one characteristic in the two groups of cases. The ease with which it is elicited may not be greater in one group than in the other; but, whereas with the grosser injuries there is simply a twitch, with the partial injuries the relaxation phase of the response is slow and deliberate, due to the presence of postural tonus.

(28) From the reflex point of view the clinical picture found in cases of complete transection of the spinal cord resembles that described as "paraplegia in flexion" by Babinski and Walshe, and the clinical picture described by the same authors as "paraplegia in extension" presents many points of resemblance to a condition which may result from less severe injury to the spinal cord. The condition of the reflexes in this latter group of cases is more comparable with that of the decerebrate animal, while the condition in the group of cases of complete transection of the cord more closely resembles that of the spinal animal.

(29) Facilitation of bladder activity can be induced only when postural reflexes are absent. Inhibition of reflex spread in the stage of reflex activity is associated with the presence of primary extension reflexes and with the preservation of control by centres situated above the lesion.

Considerations of Reflex Activity.

(30) The quality of the stimulus is an important factor in determining the character of the reflex movement. Of all stimuli, those which damage the tissues and, in the intact individual, have pain as their conscious correlate, are the most effective in provoking reflex movements in the paralysed abdominal wall and lower limbs.

(31) A stimulus, in itself subliminal, if repeated several times in quick succession will evoke a reflex reaction.

(32) A strong stimulus as a rule excites a more vigorous reaction than does a weak stimulus.

(33) The locality of the stimulus has an important influence on the character of the reflex movement excited in the group of cases of incomplete lesion of the spinal cord where there is inhibition of reflex spread. When the spinal cord has been completely transected the motor response is less determined by the locality of the stimulus.

(34) The condition of the intra-medullary parts of the reflex arcs has an important bearing upon reflex activity. In man as in animals "spinal shock" takes effect in the aboral direction only.

(35) Following transection of the spinal cord in man reflexes are depressed unequally; this seems to be due to at least three factors: (a) The degree of dependence of the reflex arc on headward centres. (b) The shock effect diminishes towards the caudal end of the spinal cord. (c) Reflexes originated by stimuli which in the intact individual have a strong affective quality suffer relatively slightly from "spinal shock."

(36) Prolonged states of toxæmia or septicæmia from urinary sepsis or foul bed-sores have a profound effect in depressing the intra-medullary parts of the reflex arcs. General fatigue and soporific drugs such as choloroform are temporary depressants of reflex action. Local fatigue may be induced by repeated excitation of reflex arcs.

(37) All other portions of the nervous system with which a reflex arc is in communication influence its activity. Thus it was found that when spinal centres distal to the lesion were completely shut off from higher control, the parts of the spinal cord with which a reflex arc was still in communication facilitated and augmented its activities; on the other hand, when the distal portion of the cord was still connected with headward centres, so that postural reflex activities were exhibited, the influence exerted upon a reflex arc by the rest of the nervous system was one of inhibition and control.

(38) After a total transection of the spinal cord the flexor muscles in both the resting and the contracting states show more tone than do their antagonists, but the tone of all the paralysed muscles remains constantly below normal in the resting state. In such cases of partial lesion of the spinal cord as have been considered in this paper no obvious difference in the tone of the two muscle groups can be demonstrated and the muscles may be hypertonic. The knee- and ankle-jerks differ in the

two groups of cases. In the former the tendon jerk consists simply of a twitch, while in the latter the twitch is superposed upon a tonic contraction. These findings would correspond in Langelaan's classification of muscle tonus to an absence of the "plastic component" in paralysed muscles after complete division of the spinal cord, whilst the "contractile element" remains. In the muscles of the patients manifesting signs of partial injury only both components are present.

APPENDIX.

Other Illustrative Cases.

No. 2.—Complete anatomical division of the spinal cord. Last normal segment third thoracic. Great reflex excitability of the isolated portion of the cord. Flexor spasms of the ventral abdominal wall and lower extremities. Knee- and ankle-jerks brisk and equal. No definite ankle clonus. Extension reflexes of the lower limbs could not be evoked. Vigorous flexion reflex. Localized contraction of the external oblique and general flexor spasm of the abdominal wall were both obtained. Cremasteric reflex present. "Mass-reflex" elicited by nocuous stimulation of abdominal wall or lower limbs. Complete loss of sensibility, somatic and visceral, in abdomen and lower extremities. Profuse sweating from arms, trunk and legs; maximum over the upper dorsal region. Automatic bladder and rectum. Facilitation. Cystitis and pyelitis not prominent.

Private H., 11th Australian Infantry, aged 24, was wounded in France on July 21, 1916. Whilst lying on the ground he received three injuries from shrapnel.

(1) Perforating wound of the back on a level with the fourth and fifth thoracic vertebræ, situated just on the inner border of the left scapula. It was directed upwards and inwards and appeared to be healthy.

(2) Perforating wound of the cheek from right to left, passing through superior maxilla and crossing the palate, causing a wound in the nasal cavity.

(3) Small superficial wound of the base of the penis. There was much extravasation of blood from it into the penis and scrotum.

With the exception of the wound in the mouth all appeared to be clean and healthy on the patient's admission to the King George Hospital in August, 1916, under the care of Dr. Farquhar Buzzard. On admission his temperature was 102° F., and pulse 100. His general condition was good. Urine was alkaline and contained much pus. Both legs and abdomen were paralysed and flaccid and somatic sensibility was lost below the level of the nipples. Tendon and superficial reflexes were absent and there was retention of urine and fæces. Small bed-sore over the sacrum.

Condition on August 25 (Thirty-five Days after the Injury).

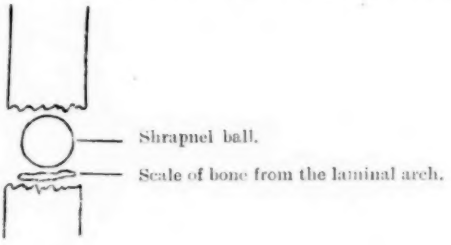
Temperature, 102° F. to normal. Œdema of the left leg. On scratching the sole of the foot the toes moved upwards.

Condition on September 8 (Forty-nine Days after the Injury).

X-ray: Shrapnel bullet lying between the third and fourth dorsal vertebræ in the middle-line. Less œdema of the left leg. Urine fairly alkaline with pus. Some discharge of pus from the right ear.

Operation on September 11 (Fifty-two Days after the Injury).

Colonel Armour removed the spines and laminæ of the third and fourth dorsal vertebræ. The cord was found to be completely divided at this level, as shown in the diagram. A shrapnel ball, $\frac{7}{10}$ in. (1 cm.) in diameter, lay inside



the theca but was not adherent to it. When the ball was removed the thecal cavity was perfectly clean. Not a vestige of cord or any other tissue traversed the space. There was a clear gap of $\frac{3}{4}$ in. (2 cm.) between the ends of the cord. A small fragment of bone from the laminal arch was found lying loose between the bullet and the free end of the caudal portion of the cord. It was removed with the bullet.

Condition on September 12 (Fifty-three Days after the Injury).

Involuntary flexion movements of the legs were present. Both knee-jerks and ankle-jerks were elicited. With plantar stimulation there was contraction of the tensor fasciæ femoris, the hamstrings and the dorsiflexors of the ankle. In the left leg there was a well-marked upgoing movement of all the toes, but in the right leg there was very little toe movement with the reflex. Slow response to stimulation of the skin of the abdominal wall.

The patient had no visceral sensations.

Condition on October 3 (Seventy-four Days after the Injury).

The muscles of the legs were very flabby and wasted. Both knee-jerks were just obtained and were much less active. Ankle-jerks were not evoked. On stimulation of the sole there was very little plantar response on the right side, but the left leg was active and the movement consisted of upgoing toes

with contraction of the tensor fasciæ femoris and the hamstrings. Abdominal reflexes were all very delayed. Urine was very strongly alkaline with much pus.

Condition on October 13 (*Eighty-four Days after the Injury*).

Both patient and Sister said that the flexor spasms of the legs had been more evident since massage was begun a fortnight previous to this date. Both knee-jerks were obtained, and, when turned on to his side there was good extension of the leg. Ankle-jerk was slight on the right side and was not evoked on the left. Right plantar response gave toe movement. The slow delayed contraction of the abdominal muscles on both sides in response to stimulation of the abdominal skin was accompanied by slight flexor movements of the legs.

Condition on November 10 (112 *Days after the Injury*).

The right foot was in the dropped position and the left was at right angles to the leg. The legs were very responsive to stimulation. Both knee-jerks and ankle-jerks were present. Stimulation of the right sole by scratching with a pin gave downgoing toes with contraction of the hamstrings, but no movement at the ankle. On scratching the left sole a good response was obtained, upgoing toes with dorsiflexion of the foot and contraction of the hamstrings. The crossed response consisted of a doubtful downward movement of the toes with distinct contraction of the quadriceps and calf muscles.

Abdominal stimulation gave (1) a faint early unilateral and crossed contraction of the abdominal muscles, and (2), after two or three seconds' delay, a general contraction of the abdominal muscles and flexor spasms of the legs.

Cremasteric reflexes were elicited.

With faradism, a very strong current was required to obtain contraction in any of the muscles below the knee in either leg. It also required a very strong current to cause a contraction when the electrode was placed over the external popliteal nerve on the outer side of the fibula.

Condition on February 24 (218 *Days after the Injury*).

The following notes were made by Dr. Head and myself:—

Motion.—The legs, when not in spasm, lay on the bed a little flexed at the knee and at the hip. The feet pointed a little downwards, but the left toe was a little up. The right toe pointed downwards and there was some limitation of upward movement passively.

All involuntary movements evoked by stimulation, even by removing the bedclothes, were flexor. There was no evidence that a crossed response, either flexion or extension, accompanied a flexor spasm.

The patient recognized that the spasms occurred by the feeling in the upper abdomen above the umbilicus.

Reflexes. — Wrist-jerks normal and brisk. Knee-jerk and ankle-jerk greatly exaggerated right and left. No definite ankle clonus.

Plantars: From the sole of the foot a characteristic flexor spasm was

evoked with "extension" (upward movement) of the great toe and splaying of the four outer toes. This reflex could be evoked by scratching the inner aspect of the knee or the groin, more strongly from the left than the right. The response was evoked most easily by pricking or grasping the sole or by squeezing the thigh. There was no definite crossed extension reflex. Occasionally, on the other hand, there was distinct bilateral flexion.

Abdominal.—On dragging a pin across the abdomen, if the scratch was kept to the outer portion (i.e., right or left) of the abdomen, it was possible to evoke a localized undulation, somewhat vermicular in appearance and slow to arrive. It ran from the rectus sheath outwards and upwards to the ribs. It was not a mass-reflex but seemed to follow the external oblique according to the level of the stimulus. It was about equally evident on the two sides of the abdomen and above and below the umbilicus. Associated with this reflex there was no movement of the toe or flexion at the knee. At no time did we see the reflex cross to the non-stimulated half of the abdomen. But not infrequently the reflex was of a different character. The rectus of the same half contracted and that half of the abdomen was pulled in and rendered concave as a whole. Whenever this reflex was evoked the great toe tended to go upwards, and there was a complete flexion reflex of the leg. The occurrence of this reflex on one side might be followed by a contraction of the rectus and abdominal wall of the opposite half of the abdomen.

Sweating.—We were told that he sweated profusely from the second rib downwards for a varying distance to about the ensiform level. If the sweating came on when the arms were under the blankets, he sweated all over the arms and down to the toes, but not over the head and neck. The maximum sweating occurred over the upper thoracic region, but on this day he was dry except from about the second rib to the ensiform. He sweated when his bladder was washed out. Sweating during the bladder observations: When we started to fill the bladder he was slightly moist from the second or third rib to the ensiform. The rest of the trunk and the limbs were dry. As soon as we began to evoke automatic bladder action he started to sweat profusely. The highest limit was the clavicles; the head and neck remained dry. The whole arms sweated profusely. The trunk was wringing wet from the clavicles to the groins. Thighs, soles, and backs of the legs were also sweating, but not so profusely as the chest, abdomen, arms and back.

The pupils did not dilate nor did the face flush.

Sphincters.—A catheter was passed and 175 c.c. drawn off.

(1) Normal saline was poured in till the bladder started to evacuate. Evacuated at 250 c.c. Evacuated 135 c.c. By pressing over the bladder a further 130 c.c. were voided.

(2) Evacuated at 290 c.c. Evacuated 175 c.c. Glans penis was then rubbed and 75 c.c. more were voided. By pressure over bladder 70 c.c.

(3) Evacuated at 250 c.c. The flow was started by touching the penis. Evacuated 140 c.c. Glans penis rubbed 50 c.c. Pressure 90 c.c.

(4) 100 c.c. allowed to flow into the bladder. Penis stroked but backflow

did not start. 50 c.c. added (150 c.c. in all). Penis stroked, evacuated 30 c.c. Pressure 100 c.c.

(5) Poured in 150 c.c. Evoked flexion reflex by scratching one sole and he immediately evacuated.

These observations were of great importance. For it was shown that in a case where the spinal cord was known to be totally divided an automatic bladder evacuated at about 250 c.c. (an "8½-oz. bladder"). The bladder evacuated from 135 to 175 c.c. But if the glans penis was stroked with the finger the bladder could be got to evacuate at 150 c.c., but not at 100 c.c. Moreover, if it was filled up to 150 c.c. and then the flexor response was evoked by scratching the sole of the foot it at once evacuated.

Thus evacuation of the bladder was part of a general explosion of which the other elements were:—

(1) Flexion of the leg and upgoing toe.
(2) Abdominal reflex.
(3) Sweating.

No. 3.—Total transverse lesion of the spinal cord. Last normal segment third thoracic. Great reflex excitability of the distal end. Flexor spasms of trunk and lower extremities. Knee- and ankle-jerks brisk. No definite ankle clonus. Primary extension reflexes not obtained. Early response from scratching the sole consisted of adduction and flexion of the toes. Later it was associated with contraction of the inner hamstring muscles, and ultimately the typical flexion reflex with downgoing toes was the only response obtained. Abdominal reflexes elicited on the seventh day. "Mass-reflex" readily evoked. With his eyes shut he described his lower limbs as being in a posture of flexion. His legs from the knees to the ankles seemed to him to be shorter than normal. Sweated from the palms of the hands, from the post-axial parts of the forearms, and from the trunk and thighs. Superficial bed-sore over the sacrum. Automatic bladder and rectum. Facilitation of detrusor activity of the bladder-wall.

Captain F., aged 29, was wounded on April 6, 1917, by a shrapnel bullet in the back. His legs crumpled under him at once and he thought that they were broken. He lost all sensation from the nipples down and he had no pain. He was carried on a stretcher to the dressing station, where the wound was dressed. Viâ the field ambulance, he was sent to the Casualty Clearing Station after a short delay. He was kept there one night, and was then transferred to No. 7 Stationary Hospital, Boulogne.

Admitted to the Empire Hospital for Officers on April 10, under the care of Dr. Farquhar Buzzard, and the following note was sent with him: "Patient admitted to No. 7 Stationary Hospital April 8 with paraplegia and anæsthesia of the legs and lower portion of the trunk. Retention of urine. Vomited frequently. Slight fever. X-ray report: Penetrating wound of spine. Shrapnel bullet apparently in spine between fourth and fifth dorsal

vertebræ. Bladder emptied twice daily and washed out with argenti nit. gr. viii to the pint. Catheter passed at 10 a.m., 10-4-17." W. J. Addey, Captain, R.A.M.C.

The patient had passed urine voluntarily not more than ten to fifteen minutes before he was wounded. Catheter was passed first at Casualty Clearing Station about fourteen to fifteen hours after he was wounded.

Wound: Small wound less than 1 cm. in diameter with dry scab over it, 3 cm. to the right of the fourth dorsal spine. No exit wound.

Condition on April 13 (*Seven Days after the Injury*).

Motion.—Total flaccid paraplegia below fifth rib. No involuntary movements of the legs. No appreciable wasting.

Reflexes.—Arm-jerks brisk and equal. Knee- and ankle-jerks absent. Bulbo-cavernosus reflex present; it could be evoked by pricking either side of glans penis. Downgoing movement of the toes with adduction was elicited from both sides by scratching the sole. No palpable tightening of the hamstring tendons.

Abdominals: (1) On scratching the skin over the external oblique a localized contraction of the muscle was evoked which followed the course of the muscular fibres. Elicited from both halves of the abdomen. Not crossed.

(2) A stronger scratch applied over a larger area of skin evoked a unilateral mass response in the external oblique and the rectus. The responding half of the abdominal wall dipped down and the umbilicus was pulled to that side. Evoked on each side and was not crossed.

No erection or seminal emission in response to appropriate stimulation such as scratching the inner surface of the thighs or by rubbing the penis.

Sensation.—Broad hyperalgesic area made out extending from the second thoracic segmental area on the arms to the fifth rib. Total loss of somatic sensibility below the level of the fifth rib. He said that he experienced no sensations from the abdominal viscera.

Vasomotor and trophic changes.—No bed-sore. The skin was everywhere dry. Legs not swollen, and the skin of the paralysed parts seemed to the hand to be as warm as the face or the upper part of the chest.

Sphincters.—Complete retention of urine and fæces.

Condition on April 16 (*Ten Days after the Injury*).

Reflexes.—Knee- and ankle-jerks, cremasteric and bulbo-cavernosus reflexes were absent.

Abdominals: (1) On stimulating the skin over the external oblique by a short scratch with a pin, a local contraction of that muscle was evoked. The contraction followed more or less the direction of the muscle fibres, i.e., from the rectus sheath outwards and upwards. The rectus did not take part in the response, which was neither perceptibly delayed nor crossed.

(2) A stronger stimulus (a firmer scratch) elicited a response from a larger

muscular field. The muscular area involved was increased in a transverse more than in a vertical direction. The ipsilateral rectus contracted with the external oblique, so that part of the stimulated half of the abdominal wall flattened or dipped. It was a massive response, but like (1) was neither crossed nor delayed.

(3) It was much more difficult to obtain a response from a single segment of the rectus, by stimulating directly over it, than of the external oblique. The response was more or less general in the muscle except when the skin over the upper segment was scratched. The contraction there was more localized. A strong scratch applied to the skin over the muscle evoked a widespread response —contraction of the ipsilateral rectus and external oblique and sometimes, too, of the opposite rectus. The limbs remained quiescent.

Plantars: (1) A single prick applied to either sole gave no response.

(2) On scratching the outer half of either sole with a pin the following movements occurred simultaneously:—

(i) Adduction of the small toes, chiefly of the second toe.

(ii) Flexion at the metatarso-phalangeal joints of all toes.

(iii) Possibly extension of the two terminal phalanges of the four outer toes.

(iv) Palpable contraction of inner hamstrings and adductors of the thigh.

Flexion of the great toe did not occur till the pin was dragged over the balls of the toes towards the inner border of the foot.

The reflexogenous area for the reflex was limited strictly to the sole and, in the left foot, to the outer and front part of it. Contraction of the crossed extensors did not accompany the flexion reflex. The reflex was more definite in the right than in the left leg.

Sphincters.—Retention of urine and fæces complete.

Condition on April 27 (*Twenty-one Days after the Injury*).

Temperature 100° F. Felt out of sorts. Right leg was very swollen; the left was normal in girth. Probably thrombosis of the right femoral vein.

Motion.—No involuntary movements were occurring.

Reflexes.—Contraction of the left quadriceps was evoked by a sharp tap on the tendon, but it was not sufficiently strong to move the leg. Response not obtained on the right side. (Right leg was swollen.) Left ankle-jerk present, right absent. No ankle clonus. On scratching the sole all the toes moved down and became adducted, but the inner hamstring and tibialis anticus tendons tightened. Except for the toes the leg did not move. This response was evoked on both sides. Abdominal reflexes were easily obtained on either side.

The patient had had several erections, sometimes with seminal emissions. They were brought on by swabbing the penis with antiseptic fluid preparatory to passing the catheter.

Vasomotor changes.—Œdema of the right lower extremity was present. Sweating of the legs had been noticed by the orderly after catheterization. The sweating was confined to the upper parts of the thighs on which the waterproof sheeting had been resting.

Condition on April 29 (Twenty-three Days after the Injury).

Temperature 99° F. Patient felt better. No flexor spasms of the legs. Abdominal reflexes were easily elicited on both sides. Flexion reflexes from stimulation of the sole were very sluggish, and consisted of downgoing and adducting toes with contraction of the hamstrings and adductors of the thigh. Knee- and ankle-jerks were absent. Right leg was still very swollen, but the skin was not red. Urine: Strongly acid, 1024, faint haze of albumin (Heller's cold test), deposit of mucus and pus.

Operation on April 30 (Twenty-four Days after the Injury).

Under general anæsthesia a large flap was turned over to the right by Mr. Walton, laying bare the spines of the first to the seventh thoracic vertebræ. The muscles were separated and the spines were removed with forceps. The left lamina of the fourth was seen to be fractured and a scale of bone from it was cut free from its tendinous attachment. The fracture lay immediately below the bullet tract. An inch trephine opening was made through the laminæ of the third and then through those of the fifth. The laminæ of the fourth were cut away with forceps. The cord was not pulsating. On the part of the dura that corresponded to the fractured lamina of the fourth there was a scar, and at the same level a shrapnel ball could be felt under the dura. The dura was incised in the middle-line for about an inch (2·5 cm.) and the ball was picked out. The cord was found to be completely divided, the ends being separated by the diameter of the bullet (just over 1 cm.). When a probe was passed round the cavity the smooth inner surface of the dura was all that could be felt laterally. No cerebrospinal fluid escaped. Two fine catgut stitches closed the dural opening. The muscles were stitched together with thick catgut. A rubber drain was left under the skin-flap to be removed in three days.

Condition on May 3 (Twenty-seven Days after the Injury).

Tube was removed and the wound looked well. There was no collection of fluid under the flap.

Reflexes.—On tapping the patellar tendon distinct contraction of the vasti cruris muscles occurred. Ankle-jerk was obtained in both legs. The left leg was more active than the right. No ankle clonus was obtained. The flexion reflex was more easily obtained than when last noted, and was elicited by nocuous stimulation of the sole.

Condition on May 5 (Twenty-nine Days after the Injury).

The patient had almost completely recovered from the operation.

Motion.—Involuntary movements of the legs were of rare occurrence. A spasm consisted of upgoing toes with contraction of the inner hamstrings, which, however, was not sufficient to flex the knee. The legs had not wasted appreciably, and the tone of both flexors and extensors was below normal, of the latter perhaps more than of the former. The abdominal recti frequently fell into spasms, without the legs moving at all. Sometimes both recti jerked at

once, but more often the spasm was unilateral. The left rectus was more active than the right. Sometimes the contraction of one rectus was followed by contraction of the other. The oblique muscles were not involved in the spasms. During a spasm, the part of the abdominal wall that corresponded to the rectus flattened while the flank bagged. The umbilicus was not pulled to the contracting side. The tone of the abdominal recti between the spasms was below normal, and the oblique muscles though not toneless were distinctly flabby.

Reflexes.—(1) Flexion reflex: The threshold value of the stimulus was high even in the sole. The central focal area of the reflex was the outer part of the sole. Noxious stimuli (scratching, pinching, or squeezing) were effective. The receptive field for the reflex extended in both legs from the planta to just below the knee. The reflex, if anything, was more easily obtained in the right leg. The motor response was brief and consisted of upward movement of the toes, slight dorsiflexion at the ankle, flexion at the knee and hip, and adduction of the thigh. The contraction was not sustained, but fell away quickly. It was distinctly delayed, and the height of the response occurred after the brief stimulus had been removed. After-extension of the limb was passive so far as could be made out. Contraction of neither the flexors nor the extensors of the crossed leg could be made out by palpation, nor were the abdominal muscles involved in the reflex. A subliminal stimulus if repeated became adequate, e.g., a single pin-prick applied to the sole did not evoke a response, but three to five pricks in quick succession were effective. Stimulation of the outer part of the planta gave, with the flexion reflex, eversion of the foot, whilst the response evoked from the inner border of the planta was accompanied more by inversion of the foot.

(2) No extensor-thrust of the lower extremity could be obtained either by pressure with the hand or by pressing a bottle containing cold water on the sole.

(3) Tendon jerks: Hamstring jerks obtained by tapping on the finger placed over the hamstring tendons were brisk, right and left. Active extension of the limb at knee and ankle resulted from sharply tapping the tendon of the quadriceps cruris and calf muscles respectively. A crossed response was not observed in the opposite limb either in the flexor or extensor muscles to accompany the tendon jerks. Three or four brief clonic movements of the calf muscles were obtained when either foot was jerked up sharply. A sustained ankle clonus could not be evoked.

(4) Abdominal reflexes: (*a*) A pin-prick applied to the skin over the external oblique resulted in a delayed local contraction of that muscle. On dragging the pin over the skin the contraction followed the course of the muscle fibres. The rectus did not respond with the oblique unless the stimulus was very strong or was applied to the skin near it. The response was not crossed. (*b*) Contraction of the rectus alone was evoked when the skin over the upper part of the muscle close to the ribs was scratched. The whole muscle responded, but most actively in its upper part. It was difficult

to be certain that the response was limited to the rectus when the skin over any other part of the muscle was stimulated. A stronger scratch elicited contraction not only of the rectus but also of the external oblique of the same side, so that the responding half of the wall dipped, and the umbilicus was pulled to that side. A stronger stimulus still (a firm scratch) evoked a bilateral response, and the whole abdominal wall was retracted. When the stimulus was applied in the middle line, and was not very intense, both recti contracted sharply, so that the abdominal wall was flattened along the middle and the flanks bagged, since the oblique muscles were not involved in the motor response. A more intense stimulus at the same place evoked a response in the obliques as well as in the recti, and the patient was pulled sharply forwards. If the spot stimulated was to one side of the middle line and a mass-reflex was elicited, the muscles of the stimulated side contracted more strongly than did those of the other side. Sometimes upward movement of the toes or flexion at the knees accompanied a rectus contraction or a massive abdominal reflex response.

(5) Cremasteric reflexes: Drawing up of the testicles resulted from nocuous stimulation of the upper part of the inner surface of either thigh or from pulling the prepuce over the glans of the penis in erection.

(6) Bulbo-cavernosus reflex: When the glans penis was pricked or when it was pinched through the prepuce the muscle of the bulb contracted briskly.

(7) Erection and seminal ejaculation: Two days before the date of this note erection of the penis with emission of semen was brought on by washing the glans with antiseptic fluid preparatory to insertion of the catheter. They were readily obtained again on the above date. Stiffening of the organ, but incomplete erection, was induced by scratching the inner surface of either thigh near the perineum and by pinching the glans penis.

(8) Coitus reflex: Scratching the groin evoked distinct contraction of the ipsilateral rectus abdominis and a less noticeable response in the external oblique of the same side. At the same time the flexors of the leg of the stimulated side contracted. Scratching over the pubis evoked this reflex bilaterally, but there was no erection of the penis, or at most there was slight stiffening only of the organ. The reflexogenous area for the response extended from the genitals on to the abdominal wall for a distance of about 1 to 2 in. (about 2·5 to 5 cm.) above the pubis, on to the inner part of the groin, the upper part of the inner surface of the thighs, and sometimes to the perineum. Nocuous stimulation of the skin higher up on the abdominal wall evoked a response in the abdominal muscles only, and lower down on the legs a flexion reflex. The threshold value of the stimulus was lowest round the genitals. When the prepuce was pulled over the glans penis with the organ in erection the penis stiffened more, the testes and the scrotum were drawn up, the muscle of the bulb responded, and sometimes the recti abdominis contracted sharply, but the legs remained quiescent.

(9) The sphincter ani was tonic, and it contracted sharply on pricking the skin over the buttocks for about 3 in. (7·5 cm.) from the anus. On inserting

a finger into the anal canal the muscle behaved as follows: As the point of the finger touched the skin the muscle contracted, then as the finger entered the canal it relaxed. When the finger was resting right in the canal the sphincter closed on it and held it with a fairly tight grip.

Vasomotor and Trophic Changes.—May 6 (Thirty Days after the Injury).

At the beginning of the bladder observations, which are detailed below, the patient's skin was perfectly dry all over, and when they were finished half an hour afterwards the only parts of the body that were moist were the scrotum, the groins and the upper parts of the thighs, parts which had been covered with a towel. The orderly declared that after the bladder had been washed out the palms of the hands were sometimes covered with sweat. The small bed-sore on the right buttock was showing signs of healing.

Bladder.—On May 5 when the penis was being swabbed, before the catheter was passed, 1 oz. (28 c.c.) of urine was voided. This was the first time the bladder had passed any urine actively. At midnight, when the glans was being cleaned, again 3 oz. (85 c.c.) of urine came away. Next morning, at 11.30 a.m., there were 14 oz. (400 c.c.) of urine in the bottle, and at 5.30 p.m. 6 oz. (170 c.c.). When the bulbo-cavernosus reflex was evoked by pricking the glans penis about 15 c.c. of urine squirted out, and 160 c.c. were reflexly voided by rubbing and pinching the glans. With each pinch the urine was voided in a jet and between the pinches it continued to flow, though with diminished force. With a severe pinch the abdominal recti and the rectus femoris and hamstring muscles of both legs contracted feebly. Urine: Amphoteric reaction, slight ring of albumin with the cold nitric acid test, sp. gr. 1010, cloudy, slight deposit of pus and phosphates. A catheter was passed about half an hour after urine had been voided by pinching the glans penis and no urine was drawn off.

(1) Eusol 1 in 16,000 was poured slowly into the bladder till a backflow began. Evacuated at 365 c.c. Evacuated 320 c.c. By pressing gently in the hypogastric region 80 c.c. more came away.

Bladder Observations continued, May 7 (Thirty-one Days after the Injury).

When the penis was swabbed the organ erected and semen was voided. Catheter was passed and 230 c.c. were drawn off.

(2) Fluid was poured slowly into the bladder through a burette attached to the catheter. Evacuated at 350 c.c. Evacuated 350 c.c. Gentle pressure over the hypogastrium brought away 5 c.c.

(3) Fluid poured into the bladder. Evacuated at 375 c.c. Evacuated 370 c.c. By pressure over the bladder, 15 c.c.

(4) 200 c.c. of fluid were poured in and a flexion reflex was induced by scratching the sole of the right foot. The bladder fired off and evacuated 150 c.c. By pressure over the bladder 50 c.c. more came away.

(5) 100 c.c. were poured in. Flexion reflex induced from the right foot by a squeeze. Fluid rose in the burette and remained stationary for a few seconds

and then went back into the bladder. At 150 c.c. a flexion reflex was again evoked by a similar stimulus. As before, the column of fluid rose in the burette, but it did not rise far and, when the flexor spasm subsided, the fluid ran back into the bladder, after remaining stationary for a short time.

Condition on May 31 (*Fifty-five Days after the Injury*).

Since the date of the last note the patient had been improving steadily in his general health and since May 24 had been out every day in a spinal chair. His temperature was normal.

Motion.—Flexion movements of the legs were much more frequent and vigorous. Extensor spasms had never been known to occur. The left leg was usually more active than the right, but the relative activity of the legs varied from day to day. In a spasm the limb flexed at the hip and knee, became adducted at the hip, dorsiflexed at the ankle and the toes moved up. Crossed extension did not occur, but crossed flexion frequently followed a flexor spasm of the leg. The crossed limb usually began to move when the spasm in the other limb was at its height. Sometimes both lower extremities went into flexor spasm simultaneously. Sometimes a spasm originated in the rectus abdominis of one side and spread to the ipsilateral leg, so that in the spasm the patient was pulled to the contracting side and the knee jumped up. The spasm might spread to the other rectus abdominis and to the other leg or a bilateral simultaneous spasm might begin in the abdominal muscles and involve the limb flexors. According to the patient the abdominal muscles never fell into spasm without being accompanied by flexor movements in the lower extremities. In a flexor spasm, flexion of the limb was not maintained for long. The leg quickly fell straight again, apparently from the action of gravity only. Often the toes were the only parts of the limb that moved, though the hamstring muscles invariably contracted simultaneously. This was the minimal flexor reflex motor response of the lower extremity.

Wasting: The legs were only slightly wasted, the muscles having filled out since the spasms had become more frequent. The vasti extensors had suffered more than the other muscles.

Tone of the muscles: (1) Flexors of the legs and the abdominal recti. During a spasm the tone of these muscles was considerably above normal. Great force had to be expended to overcome a flexor spasm. Muscular tonus between the spasms was a little below normal. The muscles dimpled on pressure more than do the flexors of a non-paralysed leg and their form was not quite so rounded: but with the increased reflex activity the tonus of the muscles had improved.

(2) Extensors of the legs and the oblique muscles of the abdominal wall. During active contraction of the vasti cruris and calf muscles, as elicited by tapping their respective tendons, the tone of these muscles was greater than when last noted. The contraction was sharper and was not so delayed, but it showed no after-prolongation. So also with the oblique muscles of the abdominal wall. The tonus of the muscles in the resting state was considerably less than that of the recti abdominis and of the flexors of the

lower extremities, though it showed an increase since the previous note was made. The muscles were firmer and had more shape and on tapping the patellar tendon the leg extended at the knee for the first time. Both resting and contractile tonus of the flexors of the lower extremities and of the abdominal wall was considerably greater than that of the extensors of the lower limbs and of the abdominal oblique muscles.

Reflexes.—(1) Tendon reflexes: Arm-jerks were brisk and equal. Knee-jerks: On tapping the patellar tendon a quick response was obtained and the leg extended on the thigh. The contraction of the quadriceps cruris muscle was not maintained. The twitch was the only component evident. The response was about equal in the two lower extremities. No knee clonus. Ankle-jerks present and equal on both sides. They were similar to the knee-jerks in that the contraction was composed entirely of a twitch and showed no after-prolongation. Three to six brief and unequal clonic jerks of the foot were evoked when the calf muscles were stretched sharply. Hamstring jerks were greatly exaggerated and equal on the two sides. They differed from the knee-jerks and ankle-jerks in that they were more vigorous and not so delayed.

(2) Flexion reflex: The only toe response obtained by scratching the sole of the foot was an upgoing and fanning movement. With a stimulus of moderate intensity the toe movement never occurred as an isolated phenomenon but was invariably accompanied by contraction of the other limb flexors, so that the response consisted of flexion at hip and knee, adduction of the thigh, dorsiflexion of the foot and upgoing toes. With a just liminal stimulus it was very difficult to be sure that the limb flexors other than the "extensors" of the toes took part in the reflex. But as the limbs were well covered with fat a minimal contraction of the hamstrings might easily have escaped detection. The rectus femoris and tensor fasciæ femoris were involved in the flexion reflex of the lower extremity. Nocuous stimuli (squeeze, prick, scratch, &c.) were alone adequate and the central focal area for the reflex was the sole. The receptive field extended to the groin and abdominal wall. Certain parts seemed to be more reflexogenous than others. For example, the threshold value of the stimulus was lower on the anterior aspect of the leg over the pretibial muscles than on the posterior aspect over the calf muscles. Again it was lower on the posterior aspect of the thigh than on the anterior aspect. The stimulus had to be more intense as it passed upwards over the sensory segments. The motor reflex response varied to a certain extent with the locus of the exciting stimulus. Thus when the outer part of the planta was scratched the foot tended to become everted and dorsiflexed, and when the inner edge of the planta was the seat of stimulation the foot became inverted a little and dorsiflexed. Again, by pinching the skin on the outer aspect of the thigh the tensor fasciæ femoris contracted more vigorously than did the other flexors and the toes scarcely moved. The maximum toe movement was obtained by stimulation of the sole. When the posterior aspect of the thigh was scratched, the hamstring muscles responded most vigorously and the toes moved hardly at all. The only crossed reflex evoked was flexion, chiefly of the

knee. In the flexion reflex, contraction of the muscles was maintained for two or three seconds. I satisfied myself that the straightening of the limb which followed was due entirely to gravity and to relaxation of the flexors and not to contraction of the extensors. This was confirmed by palpation of the muscles.

(3) Abdominal reflexes: External oblique response. A scratch applied to the skin of the flank evoked a motor response in the external oblique which followed the course of the muscle fibres. Contraction of the ipsilateral rectus accompanied it if the area stimulated was near the sheath of the rectus or if a "mass-reflex" was elicited. With the local external oblique contraction, the muscles of the lower extremities were not involved nor was the response crossed.

Rectus abdominis reflex: This was most easily obtained as a bilateral response by pricking or scratching the skin over the linea alba. The abdominal wall was flattened along the middle line and the flanks bulged more. The response involved the whole of each muscle but tended to be strongest in that part of it which was subjacent to the stimulated point in the skin. An ipsilateral rectus response could sometimes be obtained by scratching the skin over the upper part of the muscle near its costal insertion. With a moderately vigorous reaction the hamstrings of the homolateral lower limb contracted and the toes sometimes moved up.

"Mass-reflex": By stronger stimulation a general flexor spasm of the ventral abdominal wall and of the lower extremities could be evoked. The response was bilaterally symmetrical in its onset and amplitude when the locus of the stimulus was in the middle line. It was easier to evoke contraction of the abdominal muscles with flexion of the lower limbs by scratching the sole than it was to obtain a flexor spasm of the legs by stimulating the skin of the abdominal wall—i.e., the spread of impulses in the cord seemed to be freer headwards than caudalwards.

(4) The "coitus reflex" and its components: Erection was evoked with ease by handling the penis or scrotum or by passing a catheter along the urethra. Priapism and emission of semen were of common occurrence. By manipulating the lower extremities for a short time, so as to evoke several flexion reflexes in succession, stiffening of the penis was induced. It was also obtained by scratching the skin of the abdominal wall above the pubis and of the inner surfaces of the thighs. Contraction of the muscle of the bulb was elicited by pricking the glans penis or by drawing the prepuce forwards over the glans when the penis was in erection. With this movement, the organ stiffened a little more, the testicles were drawn up and the scrotum wrinkled slowly. The bulbo-cavernosus muscle was felt to contract. The recti abdominis responded sharply and almost simultaneously, though a little delayed, both lower extremities flexed. The prepuce was then pushed back, uncovering the glans, and the muscles relaxed so that the penis became softer, the testicles and scrotum dropped somewhat, the abdominal wall was less tense and the lower limbs fell straight again. Erection of the penis could be inhibited by nocuous stimulation.

Sensation.—(1) Posture of the lower extremities: For about a fortnight he had thought that his legs from the knees to the ankles had grown shorter, the feet having approached the knees. He declared that he was quite aware of his thighs, knees and feet, but he had practically no knowledge of his legs between the knees and ankles. The feet felt as if they were detached from the legs. This was the usual description he gave of his lower limbs when his eyes were shut. Sometimes the legs felt as if they were abducted, the knees being flexed and the soles of the feet flat on the bed. Occasionally he thought that the right foot was below the left supporting it, or that it had got twisted inward.

(2) Other sensations referred to the lower limbs: About a fortnight previously he said he felt pain in the right knee. Both thighs ached at times as if the muscles had been strained by a hard game of football. The skin on the anterior aspect of the thighs seemed to him to be "drawn and tight." Other sensations were complained of, such as a feeling of abdominal distension when an enema was administered, and an inflamed feeling round the anus. After the bladder had been emptied by catheter he declared that his bladder felt full.

(This patient was extremely anxious to help in the examination, and had a vivid imagination. In consequence his statements were somewhat untrustworthy.)

Vasomotor and trophic changes.—At this date the patient was sweating very little, and when he did so the moisture was confined to the palms, the lower part of the forearm, post-axial more than pre-axial, and the upper part of the chest from the clavicles to the nipples, or occasionally to the ensiform. Sometimes after catheterization the thighs, over which a towel had been placed, were moist. The sweating was never profuse. It could be excited by inducing flexor spasms of the lower limbs, by catheterization, by distending the rectum with an enema, and by movement of the body, as when he was lifted in and out of a chair. The bed-sore over the right buttock was about 3 cm. in diameter and was clean and showed signs of healing from the edges. It was quite superficial.

Observations on the Bladder with Dr. Head on June 6 (Sixty-one Days after the Injury).

Urine: Faintly acid, 1015; no albumin (Heller's test), no deposit. He had passed no urine for four hours. On swabbing the glans penis urine was not voided. Erection began. Squeezing the penis, deep breathing by the patient, and pressure on the hypogastrium failed to evoke evacuation. The catheter was inserted and 250 c.c. were drawn off.

(1) Sterile warm water was allowed to flow into the bladder through a burette fixed into the catheter. The head of pressure was kept as low as possible. Evacuation occurred at 300 c.c., and 305 c.c. were voided. By pressure on the hypogastrium, 15 c.c.

(2) Fluid allowed to flow in. Evacuated at 395 c.c. Passed 390 c.c. By pressure 5 c.c.

(3) Fluid poured in. Evacuated at 380 c.c. Passed 380 c.c. By pressure 0 c.c.

(4) 100 c.c. of fluid inserted. Then sole stimulated rhythmically (scratching). No result. At about 165 c.c. the column of fluid in the burette began to hesitate with each scratch. Evacuated at 185 c.c. Passed just under 190 c.c. On pressing on abdomen 4 c.c. (under 5 c.c.) came away. Each scratch on the sole evoked a typical flexor spasm.

(5) 100 c.c. of fluid were allowed to pass into the bladder. The sole was rythmically scratched. At 170 c.c. the column hesitated, and at 180 c.c. evacuation occurred. 180 c.c. were voided. Only a few additional drops were obtained by pressure on the abdomen.

(6) 10 c.c of fluid were inserted and the patient was told to take a deep breath. Nothing happened. After every 10 c c. the patient breathed deeply. At 40 c.c. the column remained stationary for a moment. At 60 c.c. it moved up a little, and at 80 c.c. evacuation occurred. 80 c.c. were voided. Nothing further could be obtained by pressure.

(7) The last experiment was repeated. At 40 c.c. the column hesitated, at 50 c.c. it was stationary for a moment, at 60 c.c. it rose a little, and at 70 c.c. the bladder evacuated, passing 75 c.c. Nothing was recovered by pressure.

No. 4.—*Complete transection of the spinal cord at level of ninth thoracic segment. Vigorous flexor spasms of lower extremities. Knee- and ankle-jerks easily obtained. No definite ankle-clonus. Early flexion reflex consisted of contraction of hamstring muscles and downgoing toes. Later it became true to type. Abdominal reflexes absent. Incomplete coitus reflex evoked. "Mass-reflex" obtained. Girdle pains round the lower abdomen and buttocks were induced by the introduction of a catheter into the urethra and by the administration of an enema. Sweating from the insentient skin only. Bed-sore. Automatic bladder and rectum. Facilitation. Two slight attacks of pyelitis.*

Captain H., aged 32, was wounded on March 16, 1917, at 2.30 p.m. He was walking in the open when a shell burst 10 yards to the left and in front of him. He thinks it was this shell that caused the damage, though the wound was to the right of the spine. He was knocked down and was unable to get up again. His mind was perfectly clear the whole time, and he remembers distinctly that he thought that both his legs were broken, and that he had no feeling in them. He was not aware that the abdomen was affected. He had no pain until he was being carried back to the Regimental Aid Post. The jolting gave rise to severe pain in the back over the wound. The skin round the upper part of the abdomen ached, and was tender to touch or to rubbing of the clothes. The next morning he was conveyed to the Casualty Clearing Station, and remained there for two days. Transferred to No. 2 Red Cross Hospital, and then to England. The following note accompanied him: "Gunshot wound of the spine. Immediate paralysis.

Entry right chest posterior. No exit wound. Level D 8. Complete paralysis. Retention of urine and incontinence of fæces. Slight temperature. No operation."—Major Austin, R.A.M.C. He remembered emptying his bladder about one and a half hours before he was wounded. A catheter was first passed at 10 p.m. on the 16th—i.e., seven and a half hours after the injury.

He was admitted to the Empire Hospital on March 22, under the care of Dr. Kinnier Wilson. The journey had upset him considerably, and his condition was poor. He had spasms of coughing, and brought up frothy mucus. There was no desire for food. He complained of superficial pain and tightness round the lower chest and upper abdomen, just above the level of lost sensation. Complete sensory loss up to 1 cm. above the umbilicus. Complete flaccid paralysis of the abdominal wall below the umbilicus and of the legs. The umbilicus moved up slightly when he lifted his head. No involuntary movements of the legs. The physiological flexors of the limbs were not so devoid of tone as were the extensors. Abdominal and cremasteric reflexes, knee- and ankle-jerks were absent. On scratching the sole with a pin the toes went down and the inner hamstring tendons could be felt to tighten. This response was obtained on both sides. No crossed reflex. There was complete retention of urine and fæces. Both sphincters were tonically contracted. The legs were not swollen, and the skin was dry. The legs and abdomen were warm to touch. Entry wound: Small wound with black sloughs situated 3 in. (7·5 cm.) to the right of the spine in the ninth interspace. A probe could not be passed into the chest. No exit wound. Round the wound the chest was dull on percussion and the air entry was poor. Rhonchi and coarse râles were heard round the wound.

March 28: Stereoscopic X-ray photographs were taken of the dorsal spine. A piece of metal was seen to be lying over the tenth dorsal vertebra and to the right. There was no sign of fracture of the spinous processes or of the laminæ, but a deep shadow cast by the diaphragm and liver obscured the view.

The patient was sleeping badly and was very depressed and morbid. He had no appetite. The chest was less dull on percussion, but râles were numerous over the same area. Distressing spasms of coughing, especially during the night and in the morning. Sputum: tenacious, mucous, a little frothy. Wound was very much cleaner.

Condition on March 30 (*Fourteen Days after the Injury*).

Motion.—Complete loss of voluntary power below the umbilicus. The umbilicus moved up about 2·5 cm. when the head was raised. No involuntary movements of the legs and no wasting of the muscles. The muscles of the lower abdominal wall and of the legs were flaccid, but the limb flexors were less flabby than the limb extensors.

Reflexes.—Arm-jerks were present and equal. Knee-jerks, ankle-jerks, and ankle clonus, bulbo-cavernosus, cremasteric reflexes and erection of the penis

were not obtained. Epigastric reflexes were present, but below that level the abdominals were absent.

Plantars and flexion reflex: On scratching the left sole the minimal motor response was contraction of the inner hamstrings with downgoing toes. With a stronger stimulus, there was flexion at the knee and ankle, brief downward movement of the toes followed by an upward movement. No crossed response was obtained in flexors or extensors. The reflex response in the right leg was similar to that in the left, except that occasionally upward movement of the toes occurred without an initial downward movement. In the right leg the receptive field for the reflex reached the junction of the upper and middle thirds of the thigh, and in the left leg to the junction of the lower and middle thirds of the thigh. The threshold was lowest in the sole and increased on ascending the limb. Pricking or scratching the perineum or upper parts of the inner surfaces of the thighs did not evoke either unilateral or bilateral extension of the legs, nor was extension elicited by pressing the sole with the thumb or palm of the hand. In response to pin-prick of the skin for 8 to 10 cm. around the anus, the sphincter contracted briskly.

Sensation.—Complete loss of sensibility up to 2·5 cm. above the umbilicus. Broad area of hyperalgesia above that level. It reached in the middle line to within 7 cm. of the lower end of the sternum and laterally to the eighth interspace.

Sphincters.—Retention of urine and fæces complete. On attempting to pass the finger into the anal canal the sphincter contracted more firmly as the point of the finger touched the skin. When the finger entered the canal the sphincter relaxed, but contracted again and held it with a light firm grasp when the finger was kept motionless. As it was being withdrawn the sphincter again contracted firmly on it.

Vasomotor and trophic changes.—A small area of skin about 1 cm. in diameter over the left tuber ischii was red, and the surface was broken. The skin of the heels was red, but not unhealthy looking. No sweating, and the temperature of the skin of normal and paralysed parts felt the same.

April 12 (*Twenty-seven Days after the Injury*).

Erection of the penis and drawing up of testicles and scrotum were noticed when the organ was handled.

April 14 (*Twenty-nine Days after the Injury*).

Operation: Under chloroform, ether and oxygen anæsthesia, Mr. Walton turned down a flap from the left of the spine. An incision was made on either side of the spines and the muscles were scraped away from the laminæ. The spine of the tenth thoracic was removed with forceps, and then those of the eighth and ninth vertebræ. A trephine opening was made through the lamina of the tenth. The ligament and the soft tissues corresponding to the cord and the extradural fat were grey and appeared to be disorganized. Trephined through the eighth thoracic laminæ. Cord pulsating normally below the

opening, and the extradural fat and vessels appeared to be normal. Laminæ of the ninth were clipped away with forceps. At a point corresponding to the lower border of the ninth vertebra the cord was seen to be completely divided. The gap extended down to the upper border of the eleventh vertebra at least. The laminæ of the eleventh were not removed. A ragged piece of metal 2 cm. long and 1·5 cm. broad and over 0·3 cm. deep was picked out with forceps from the upper cut end of the cord. It had penetrated for a short distance into the anterior wall of the canal of the ninth thoracic vertebra. The muscles were stitched together and the wound was closed. A rubber tube was left under the flap for twenty-four hours.

Condition on April 26 (*Forty-one Days after the Injury*).

Bladder.—Catheter passed. 500 c.c. drawn off.

(1) Eusol (1 in 16,000) poured slowly into the bladder through the catheter. Evacuated at 120 c.c. Evacuated 140 c.c. By pressure on the hypogastrium 0 c.c.

(2) Solution poured into the bladder. Evacuated at 110 c.c. Evacuated 130 c.c. By pressure on the hypogastrium 0 c.c.

Condition on April 27 (*Forty-two Days after the Injury*).

The ether anæsthetic had upset the bronchial condition again. On the day following the operation the temperature rose to 101·8° F., pulse 100, respiration 24. Coarse râles could be heard over the greater part of the right chest behind. Spasms of coughing were very frequent, and large quantities of frothy mucus were brought up. On April 16 he had a rigor, and the temperature rose to 104° F., but it quickly fell again, and on April 17 it was almost normal. He was coughing less and the sputum was diminished, but he complained of pain round the chest. On April 18 the temperature rose a little again, and it did not finally become normal till April 24. No signs of consolidation could be made out in the chest. Râles had diminished in number and coarseness, less sputum was being brought up, and the coughing was less distressing. The stitches were removed on that date. The wound had healed and looked well.

Motion.—(1) Spasms: For the week following the operation the reflex activity of the legs was a little diminished, but on this date the spasms were more frequent again. The left was, if anything, the more active of the two limbs. The movement in each spasm was one of flexion at the hip, adduction of the thigh, flexion at the knee, dorsiflexion at the ankle, and upgoing toes. Both legs occasionally jumped at the same time, but usually the spasm was unilateral. For a long time the flexion movements were confined to the left leg, and the intervals between the jerks varied considerably. The intervals in seconds for a consecutive series were 15, 50, 2, 2, 10, and then for a minute every 5 seconds, then 15, 5, 10.

(2) Tone of the muscles: (*a*) Between the spasms. The tone of the flexors and extensors was below normal, but of the extensors more than of the

flexors. (*b*) During a spasm: The tone of the flexors increased, while the extensors seemed to have even less tone than in the resting state of the limb.

(3) Wasting: There was considerable wasting of both legs, of the quadriceps cruris and calf muscles more than of the hamstrings and the anterior tibial group. The vasti especially were smaller than they should have been.

(4) Posture of the legs: Between the spasms the legs lay straight out in bed with the feet slightly plantar-extended and the toes pointing. The whole leg was rotated a little outward and the foot was somewhat inverted.

Reflexes.—On tapping the patellar tendon the quadriceps contracted and the tendon tightened. The contraction was not sufficient to extend the leg. The response was better in the left than in the right leg. Contraction of the calf muscles was evoked by tapping the tendo Achillis, left more than right. No ankle clonus.

Flexion reflex: (*a*) Adequate stimuli: Noxa such as pricking, scratching, pinching or squeezing evoked a motor reflex response. (*b*) The time of response was slightly delayed. (*c*) Character of the response: The movement was one of flexion at the hip, adduction of the thigh, flexion at the knee, dorsiflexion at the ankle, and upgoing toes with fanning of the four outer toes. The maximum movement occurred a little after the brief stimulus (prick) had been withdrawn. The limb continued to flex so long as the stimulus was applied to the sole up to a certain point. After about twelve to fifteen seconds it fell straight again, though the foot was still being pinched or scratched. I was not satisfied that contraction of the contralateral extensors accompanied the flexion reflex. The abdominal rectus was not involved in the reflex. The response was equally brisk in both legs. (*d*) Reflexogenous area: The threshold was lowest in the sole, but a complete reflex response could be obtained by scratching or pinching any part of the limb. It could not be evoked from above Poupart's ligament. The threshold value of the stimulus increased the farther away was the part stimulated from the sole of the foot. When the perineum was pricked both legs flexed simultaneously. Handling the penis or pricking the glans gave the same bilateral response, and with it the muscle surrounding the bulb of the urethra contracted; the testicles were also drawn up. I was not certain that the penis stiffened, but certainly no definite erection of the organ occurred. The legs constantly flexed together when the catheter was inserted, and when the bladder was expelling the last few drops of the bladder wash. The spasms were sometimes very violent on these occasions.

Ipsilateral extension could not be evoked by stimulating any part of the legs or perineum. Abdominal reflexes were absent. A cremaster response was obtained, right and left, by scratching the inner surfaces of the thighs near the groin. Bulbo-cavernosus reflex evoked by pricking the glans penis. The sphincter ani contracted sharply in response to pricking or scratching the skin near the anus.

Vasomotor and trophic changes.—(1) Sweating: He had never sweated

from the paralysed parts. Even the buttocks enclosed in the air-ring were always dry according to the nurse. With aspirin and when he had a high temperature he sweated only from the face, neck, arms, shoulders, chest and upper part of the abdomen. The skin of the legs and lower abdomen was rough in places. Sweating could not be excited by evacuation of the bladder, administration of an enema, or a flexion reflex. The legs were not swollen and to the hand they felt as warm as the face or chest.

(2) Trophic changes: The superficial sore over the left tuber ischii and another to the right of the middle-line over the lower part of the sacrum were clean and showed signs of healing.

Bladder and sphincters.—(1) The sphincter ani was tonic. When the finger was being passed into the anal canal, as the point touched the opening the sphincter muscle contracted more, so that the skin became wrinkled. The resistance continued till the finger was just within the canal; then it relaxed and remained so till the finger, now well in the canal, had ceased to move. Then the finger was held there with a fair degree of tightness by the sphincter. When an enema tube was inserted the sphincter reacted in the same way as when the finger was passed. A Higginson's syringe was used to introduce the fluid. The bowel reacted first to one syringeful (about 30 c.c.), though this was an unusually small amount. As a rule it reacted to about 85 c.c. to 115 c.c. When sufficient fluid had been introduced the bowel suddenly contracted, the sphincter relaxed and fluid mixed with faeces was thrown out all at once into the receiver. There was no dribbling. For the next reaction more fluid had to be pumped in as there was now more room for it. The reaction was identical with the first. Occasionally the contents of the rectum, fluid and faeces, might be expelled, not by one but by two or more contractions.

Condition on April 29 (Forty-four Days after the Injury).

(2) Bladder.—When the glans penis was swabbed with weak antiseptic fluid prior to insertion of the catheter, 90 c.c. of urine were passed. Catheter passed. 810 c.c. drawn off. Glans penis squeezed and about 5 c.c. were voided. Pressure on hypogastrium brought away about 5 c.c. or less. Before the catheter was passed he complained of cramp-like pains in the lower part of the abdomen and along the inner surfaces of the thighs. The pains were continuous. They started with a bad spasm of the legs and were relieved when the bladder was emptied.

(1) Eusol 1 in 16,000 poured slowly into the bladder through a glass funnel attached to the catheter. After 50 c.c. had been poured in the fluid began to come back. The backflow was started by the patient holding his breath. Evacuated 40 c.c. of clear fluid. Glans penis pinched and 10 c.c. clear fluid returned. Pressure on the hypogastrium brought away 10 c.c. dilute urine.

(2) After 100 c.c. of fluid had been introduced, respiratory fluctuations in the column of fluid in the tube began to appear. Evacuated at 150 c.c. Evacuated 140 c.c. in a steady but not very forcible flow. All the fluid was clear except about the last 10 c.c. which was dilute urine. This last came

away in a final spurt after the steady flow had gone down to a dribble. Glans penis pinched and he passed 10 c.c. dilute urine. Pressure on the hypogastrium brought away 10 c.c. of dilute urine.

(3) Fluid poured in. Respiratory waves were very pronounced after 100 to 150 c.c. had gone into the bladder. Evacuated at 300 c.c. Evacuated 290 c.c. Glans penis pinched and he voided 10 c.c. of very dilute urine. Pressure on the hypogastrium brought away 5 c.c.

(4) 100 c.c. of fluid poured into the bladder. Flexion reflex was induced by scratching the sole. No evacuation occurred. 25 c.c. were added and flexion reflex was again evoked. No evacuation occurred nor did any fluid appear in the glass tube. 25 c.c. added. Foot scratched. No result except flexion of the leg. 50 c.c. added. Flexion reflex induced and bladder evacuated, i.e., at 200 c.c. Evacuated 200 c.c. Glans penis pinched and he passed less than 5 c.c. Pressure on the hypogastrium brought away less than 5 c.c.

During these observations care was taken to pour the fluid into the bladder slowly and not more than 25 c.c. was in the funnel at one time. The head of fluid was never more than about 15 cm. Syphonage was carefully prevented when the bladder was evacuating. The indication of active contraction of the bladder musculature was the rising of the column of fluid in the glass tube.

When the catheter was being passed along the urethra, as the point touched the sphincter, the muscle could be felt to contract and the resistance increased. With gentle manipulation the resistance diminished and the catheter was allowed to pass into the bladder. As it lay in the canal of the sphincter it was held there with a fairly tight grasp. On trying to pull it out the grasp was felt to increase.

When the orderly was washing the penis and scrotum after the bladder observations the penis became semi-erect. That was the first sign of erection since the operation.

Urine: Faintly acid, 1008, no albumin or deposit.

Condition on May 4 (Fifty Days after the Injury).

Sensation.—The skin just above the upper limit of the insentient area was much less tender to touch. The patient complained of severe cramp-like pains in the lower abdomen, in the groins and testicles, and in the upper parts of the thighs. He had the feeling as if an iron band was gripping him round the buttocks and was being screwed up tighter and tighter. It was not continuous but came on in spasms. He thought the spasms were brought on by being moved about and that lying perfectly still relieved them. After waking up from a good sleep he was certain he had no pain at all in these regions, but as soon as he began to pull himself up by the pulley, or to be moved about in bed, the tight feeling in the lower abdomen became evident and spread to the groins and testicles. He declared that the pain could be brought on or intensified by passing the catheter, and he believed he could tell that the instrument was passing along the urethra. When tested with his eyes shut however his answers were never right. He described certain "feelings" in

the legs. "At times," he said, "if I close my eyes I think there are tight strings running along the inner sides of the thighs to the ankles and that they are in vibration. The legs too feel as if they were being pulled out straight. When the taut strings are vibrating the cramp-like pains around the lower part of my abdomen and buttocks are relieved for the moment. Sometimes the skin over my buttocks feels red and inflamed and I can put my hand on the sore place." The skin when examined appeared to be quite healthy. When he had pain anywhere the legs felt as if they were tucked up under him in extreme flexion. The degree of flexion depended on the amount of pain. At times one leg seemed to him to be crossed over the other and flexed at the knee, though they were really lying straight out in bed and were not in spasm.

Condition on May 17 (Sixty-three Days after the Injury).

At 10 p m. on the previous night he had a slight rigor and the temperature rose to over 100° F. He did not complain of pain. On this date the temperature was just 100° F., and he had a slight headache. He felt comparatively well. Slight tenderness on palpation over the left kidney was made out but none on the right side. Left rectus abdominis was more rigid than the right. The hyperalgesic area round the upper abdomen was very sensitive, more than it had been for some time. Involuntary flexor spasms had been very frequent for about a week. On this date they were few and feeble.

Condition on June 8 (Eighty-five Days after the Injury).

The patient had recovered from his febrile attack and was feeling much better.

Motion.—(1) Spasms: Flexor movements of the lower extremities had been frequent and vigorous. The left leg was more active than the right but the difference was not so marked as it had been. Frequently the spasms were bilateral and simultaneous, involving the recti abdominis. They usually originated in the lower limbs but occasionally they spread from the abdominal wall. When the patient got back to bed, after being out in the spinal carriage, the flexor spasms were more violent than at other times and the intervals between them were shorter. Extensor spasms of the lower extremities had never been observed.

(2) Wasting of the lower limbs: After the attack of pyelitis both lower limbs had shrunk a little and the wasting was more or less general, and not confined to one muscle group.

(3) Tone: The extensors (quadriceps cruris and calf muscles) were definitely more pliable and less resistant to pressure than were the flexors.

Sensation.—When the catheter was being passed along the urethra, he complained bitterly of intense cramp-like pains with a burning feeling in the lower abdomen and at the base of the penis. They were not present before the catheter was inserted and they remained, though less acute, for some time after it had penetrated into the bladder. As the instrument was being removed, after the bladder lavage, the intensity of the pain increased again. With

this pain the muscles of the lower limbs felt tight and hard as if they were bound in iron. The limbs, he thought, were flexed. These painful sensations constantly accompanied catheterization and they never varied in character. Most insistent in the daytime, they were excited definitely with catheterization during the night, when he was half-asleep. The administration of an enema was equally efficient in bringing them on and he maintained that they were always of the same type and had the same distribution. They gradually died away after the exciting stimulus had been removed and, until he was disturbed again, he remained almost entirely free from pain in the paralysed parts.

Violent motion of any kind was a fruitful source of trouble. When the spinal carriage, in which he was being wheeled about, was bumped over rough ground he had the cramp-like feeling round the lower abdomen and external genitals, especially in the testicles, and had almost to cry out with the pain. The tight feelings which he used to complain of in the legs were still evident at times. He said: "I still think if I close my eyes that there are banjo-strings stretching tightly from my ankles to my testicles and they often vibrate. The vibration always begins below at the ankle and passes up the strings. I feel the vibrations in both legs." The position in which he thought his lower extremities lay varied very much from time to time. Usually they seemed to be well bent and sometimes one was crossed over the other. The knees never felt so flexed now that the feet were tucked up under him. He thought that the legs were normal in length and that he was aware of the different parts of each leg. "I can feel the calf just as well as I can feel the thigh."

No. 5.—*Total transverse division of the spinal cord. Last normal segment third thoracic. Septic pneumonia. Flaccid paralysis of lower extremities and trunk below the fourth rib. Knee- and ankle-jerks, cremasteric and bulbo-cavernosus reflexes not obtained. On scratching the sole with a pin the toes went down and the hamstring tendons tightened. Complete loss of sensibility below the level of the nipples. Profuse general sweating. Sloughing bed-sore over the sacrum. Automatic evacuation of urine, irregular and incomplete. Sphincter ani tonic. Died on the nineteenth day of septicæmia. Sphincters remained tonic till within a few hours of the end.*

Captain J. was wounded on March 24, 1917, by a shrapnel bullet in the chest and spine. The following is a copy of the note sent from the Casualty Clearing Station: "Admitted March 24. Shrapnel wound of spine at level of fifth dorsal; also superficial wound over right eye. X-ray showed shrapnel ball in the body of the fifth dorsal vertebra. The wound was a little to the right of the spine. The superficial and deep reflexes were absent from about ½ in. below the nipple line. There was retention of urine and constipation. Under chloroform anæsthesia an incision was made over the spinous processes of the third to the seventh dorsal vertebræ. The laminæ on the right side were exposed and the lamina (right) of the fifth dorsal was removed. The cord was found to have been completely divided. With some difficulty the ball was removed from the body of the vertebra. A tube was inserted after all the bleeding had been stopped and the wound was closed.

"March 26: Temperature 100·8 F., pulse 104, respirations 22. He made a good recovery from the operation. Urotropine, 10 gr., four hourly. Urine drawn off with catheter morning and evening.

"March 31: Condition much the same. Temperature 99·8 F., pulse 94, respirations 26. Urine contains a small trace of albumin."—Captain W. S. Richardson, R.A.M.C.

From No. 7 Stationary Hospital he was transferred to England to the Empire Hospital for Officers on April 9, and was put under the care of Dr. Head. At the Base Hospital his urine was drawn off night and morning and the bladder was washed out with silver nitrate 1 gr. to the pint of water.

On admission he was in a very collapsed condition. He was semi-comatose, his breathing was embarrassed, his pulse was quick and irregular, and the temperature was high. His skin was covered with a cold sweat. It was evident he was in severe pain, most probably in the head, for he moaned frequently and put his hand on his forehead. The whole chest was full of coarse râles, but more particularly the right side. Distinct dulness on percussion round the wound in the chest. Signs seemed to point to fluid in the right pleural cavity. Heart sounds were feeble and the pulse was irregular. Entry wound: Large septic wound in the back of the right chest at the level of the fourth and fifth dorsal vertebræ. No sinus leading into the chest. No wound of exit.

Motion.—Total flaccid paraplegia from the nipples down. No involuntary movements of the legs.

Sensation.—Complete loss of sensibility from the level of the nipples downwards. No hyperalgesic area was made out, but the patient was in a very poor condition for testing.

Reflexes.—Arm-jerks present and equal. Knee-jerks, ankle-jerks, and ankle clonus absent both legs. Abdominals, cremasteries and bulbo-cavernosus reflexes absent. On scratching the sole with a pin the toes went down and the hamstring tendons tightened. The response was obtained on both sides.

Vasomotor and trophic changes.—Patient sweated freely all over. Septic and sloughing bed-sore about 5 cm. in diameter over the sacrum.

Sphincters.—Retention of urine not quite complete; passed a little urine reflexly. Sphincter ani tonic. Urine: Acid, 1022, no albumin or blood, but some mucus. Several false passages in the urethra. Blood came away when a rubber catheter was being passed. Catheter ordered six-hourly.

April 12: Failed steadily and died of septicæmia at 1.30 a.m. Sphincters remained tonic till within a few hours of the end.

No. 6.—*Bullet wound of chest. Severe injury to spinal cord, but not complete transection. Paralysis of lower extremities and trunk below sixth rib. Involuntary steppage movements of lower limbs. Knee- and ankle-jerks show an after-prolongation of contraction. Ankle clonus. Extensor thrust and bilateral extension reflexes obtained. Flexion reflex accompanied by crossed extension. Abdominal reflexes present. Coitus reflex associated*

with extension of the lower extremities. "Mass-reflex" absent. Complete loss of somatic sensibility below the sixth rib. Some visceral sensation retained. The lower limbs always seem to the patient extended. Automatic bladder and rectum. Evacuation of urine not facilitated by extra-vesical stimulation. Cystitis and pyelitis not prominent. Chronic dyspepsia.

Captain P., aged 30, was wounded in the back of the chest by a machine-gun bullet on October 2, 1916. He dropped like a log. He felt quite comfortable and did not know what had happened. It was only when he was picked up by the stretcher-bearers that he realized that his legs and trunk were powerless. They carried him back to the Field Dressing Station, and afterwards to the Casualty Clearing Station, where he remained for a short time before being transferred to No. 7 Stationary Hospital, Boulogne. His bladder was first emptied by catheter twenty-four hours after he was wounded. He did not feel the catheter being passed. At Boulogne, where he remained for five days, he was catheterized night and morning. No bladder lavage. At that time he was vomiting frequently and had great difficulty in breathing.

Evacuated to England on October 8, he was admitted to Queen Alexandra Military Hospital, Millbank, on the 9th. On his arrival his breathing was very embarrassed and the left pleural cavity was aspirated. A large quantity of almost pure blood was drawn off. Oxygen was given for three nights.

Transferred to the Empire Hospital on October 14 under the care of Dr. Batten. Small entry wound was found 4 cm. to the right of the fourth thoracic spinous process, and an exit wound 7 cm. to the left at the same level. On October 15, 400 c.c. of what seemed to be pure blood were drawn off from the left pleural cavity. Temperature 102° F., pulse 130, respirations 30. The bladder was emptied by catheter every six hours, and was washed out night and morning with eusol 1 in 16,000. Urotropine 10 gr., ac. sodii phos. 30 gr. every six hours. Urine: Very alkaline, 1010, much albumin and pus.

On October 20, 500 c.c. of blood were aspirated from the chest with great relief to the patient. A flexion reflex consisting of upgoing toes and contraction of the hamstring muscles was obtained by scratching the sole of either foot.

On October 25, 500 c.c. of blood were drawn off from the pleural cavity. Patient much better. Urine: Slightly alkaline, 1012, fair amount of albumin.

On November 10 there was very little dulness over the left lung, and the apex-beat was in almost the normal position.

On December 2 the patient complained of headache and nausea. He vomited on several occasions and his abdomen was distended with gas. No tenderness over either kidney. Temperature was normal. The condition of the chest from examination was good. Urine: Acid, no ring of albumin with Heller's cold nitric acid test, no deposit.

Condition on December 15 (Seventy-four Days after Injury).

Temperature normal. Slight dulness over the base of the left lung. Breathing not embarrassed. The gastro-intestinal complications had cleared up.

Motion.—Complete paralysis of lower extremities and trunk below the sixth

interspace. Muscles flabby and somewhat wasted. Involuntary steppage movements of the lower extremities went on at intervals. The feet and toes moved most. Very little movement at knees and hips. With flexion of one limb there was extension of the other, then extension of the former and flexion of the latter, and so on.

Reflexes.—Knee-jerks were brisk and equal on the two sides. No rectus clonus. Ankle-jerks were less easy to elicit than the knee-jerks. No ankle clonus. A complete flexion reflex was evoked by nocuous stimulation (scratching, pricking, squeezing) of either sole. It consisted of flexion at hip and knee, adduction of the thigh, dorsiflexion of the foot and upgoing toes. A crossed extension reflex invariably accompanied it. The threshold value of the stimulus was lowest in the outer part of the sole. When the skin of the abdominal wall was scratched there followed contraction of the ipsilateral abdominal muscles. A bilateral response could be evoked by applying the stimulus in the middle-line. A crossed reflex was not obtained by excitation of the flank. Cremasteric reflexes were elicited when the upper part of the inner surface of the thigh was pricked or scratched. With retraction of the testicles the scrotum slowly wrinkled.

Sensation.—Complete loss of somatic sensibility below the level of the sixth rib. There was no hyperæsthetic area at the upper level but the patient had a tight feeling round the chest.

Vasomotor and trophic changes.—He did not sweat from any part of the skin surface. There was a small superficial abrasion of the skin over the upper part of the sacrum.

Sphincters.—The bladder and rectum evacuated their contents automatically. Urine was voided about every two hours and from 2 to 4 oz. (50 to 120 c.c.) were expelled at a time. Urine: Acid, distinct ring of albumin with Heller's cold nitric acid test, small amount of pus, no blood. Deposit of pus and bacilli. Cultures grew a profuse growth of *Bacillus proteus* with a few colonies of *Bacillus coli*.

On January 10, 1917, he again complained of headache, nausea, loss of appetite and abdominal discomfort. At times he had actual pain in the abdomen. Involuntary movements of the lower extremities were less vigorous and frequent.

On January 26, 116 days after the injury, the amount of residual urine left in the bladder after a reflex act of evacuation was about 55 cc. Catheterization was stopped.

Symptoms of gastro-intestinal irritation were still present on February 1 but they were less prominent. Reflex activity of the paralysed parts was, perhaps, less depressed.

Condition on March 6 (155 Days after the Injury).

The patient was feeling much more comfortable.

Motion.—Total paralysis below the sixth rib. Slight wasting of the muscles of both lower extremities. Steppage movements of the feet were of

frequent occurrence, and with the flexion phase the hamstring muscles contracted. No violent flexor spasms. The tone of the muscles between the involuntary movements was below normal, of the extensors not more than of the flexors. Slight wasting of both lower extremities.

Reflexes.—Knee-jerks were very brisk, left more than right. Ankle-jerks were easily obtained, left more readily than right. Poorly sustained ankle clonus. On stimulating the sole (scratch), there followed upward movement of the toes, dorsiflexion of the foot and flexion at knee and hip. At the same time the opposite leg became extended at the knee, the foot plantar extended and the toes moved down. Flexion of the contralateral limb was never evoked as a crossed response nor could a bilateral flexion reflex be obtained by excitation of the perineum. The crossed extension reflex was broken through and replaced by flexion when a nocuous stimulus was applied to the sole. The reflexogenous area for the flexion reflex was about the same in the two lower extremities. It extended from the sole, the focal area of the field, to the junction of the upper and middle third of the leg, the threshold becoming raised the farther from the sole was the situation of the stimulus. Round the knee was a neutral area from which sometimes flexion and sometimes extension was obtained. To evoke a reflex from this area the stimulus had to be intense—e.g., pinching, squeezing or firm scratching. The threshold for a reflex was higher there than in any other part of the lower limb. Light scratching of the thigh, groin and perineum evoked an extension-reflex—i.e., extension at the knee, plantar extension of the foot, and downgoing toes. When elicited from the lower part of the field, the response was almost entirely ipsilateral. But as the spot stimulated approached the groin the reflex became bilateral though stronger on the homolateral side. From the perineum and external genital organs the response obtained was symmetrical on the two sides. The anterior and inner aspects of the thigh had a lower threshold value than the outer aspect for both superficial and deep stimulation. The posterior aspect of the thigh gave a varying response either of flexion or extension. The focal area of the field comprised the external genital organs and the perineum.

Abdominals: On scratching the skin of the flank a localized contraction of the external oblique was evoked. It ran from the rectus sheath upwards and outwards towards the ribs, following the course of the muscular fibres. The contraction followed the point of the pin and did not involve the whole breadth or length of the muscle. The response was not crossed. It could be evoked from any of the abdominal segments, but with perhaps more ease from the lower than from the upper. The muscles of the lower extremities were not involved in the reflex. The response was equal on the two sides of the abdomen.

Cremasteric reflexes were readily elicited by scratching the upper part of either thigh. The testicles retracted and the scrotum was drawn up with a vermicular movement. Bulbo-cavernosus reflex was brisk and was obtained by pricking the glans penis. Erections were frequent. They could be induced

by rubbing the inner surfaces of the thighs. Emissions of semen had not been noticed.

Sensation.—Complete loss of somatic sensibility below the level of the sixth rib. The patient described sensations which he referred to the lower part of the abdomen between the umbilicus and pubis. He felt as if his bladder was distended with cold fluid. The feeling lasted not more than a quarter of an hour. He was not sure whether it was relieved by evacuation of urine. In the afternoon about 4 o'clock, just before he had tea and after waking up out of a sleep, he was usually aware of an acute pain in the pit of the stomach which lasted for about twenty minutes. It died away when he ate something.

During the gastro-intestinal attack which he had a short time before, when his abdomen was distended with gas, he used to complain of a pain in the abdomen, which was relieved by the passage of flatus and by an enema. He often described feelings referable to the lower bowel. At times he was almost certain that he was passing a loose motion. The sensation persisted for several minutes on end. He had no reason to think that the bowels had actually been moved. He was quite unconscious of the injection of an enema and of the insertion of a catheter. Frequently he described a numb feeling in the lower part of the thighs and round the knees. It was, as a rule, more pronounced in the left than in the right leg, and, on this date, he was acutely aware of it in the left foot. This sensation was brought on by touching the leg and by washing either arm, particularly the left. This was tested, and when it was excited he declared, "It is in the knee," or "I feel my left foot numb."

Vasomotor and trophic changes.—Erythema of the skin over the paralysed parts could be readily induced by irritation of any kind. The patient never sweated. No bed-sores.

Sphincters.—The bladder was automatically evacuating all its contents except about 2 oz. (55 c.c.). Catheterization had been stopped for three weeks. The rectum was reacting reflexly. Sphincter ani tonic.

The following bladder observations were made on March 12, 161 days after the wound: a catheter was passed and the bladder emptied. Fluid was poured in slowly through a funnel. Evacuated at 170 c.c. Evacuated 180 c.c. No fluid was voided when the glans penis was pinched nor when the sole was scratched. Fluid was again poured in. Evacuation occurred at 154 c.c. Evacuated 140 c.c. Stimulation of glans penis and sole of foot brought away nothing. By pressure 42 c.c., showing that he had passed some urine meanwhile into his bladder. Fluid again poured into the bladder. Evacuated at 168 c.c. and the whole amount was thrown out. By pressure over the bladder a small amount was recovered. 56 c.c. were then introduced and the penis was pinched without result. 58 c.c. were added and the stimulus was again applied. No evacuation occurred until the bladder contained 168 c.c., when 140 c.c. were voided; 28 c.c. were recovered by pressure. Stimulation of the glans penis did not facilitate evacuation of the bladder.

Urine: Slightly acid, 1012, no albumin (Heller's cold nitric acid test), deposit of mucus and phosphates.

When the external genitals were being washed by the orderly after the

bladder observations the penis became turgid. As the hand moved over the glans the whole abdominal wall was seen to contract with a quick jerk. The response was chiefly in the recti and in their lower parts, so that the umbilicus was pulled down about an inch with each contraction. The duration of the contraction corresponded with the duration of the stimulus. If the stimulus was brief the response was equally short and sharp.

March 15, 164 *Days after the Injury.*

(1) The receptive field of the coitus reflex: This involved the penis and scrotum and extended upwards on the abdominal wall to half-way between the pubis and umbilicus, and downwards on the inner surfaces of the thighs, fading away as the knees were approached. The area for the complete reflex did not reach the knees. For example, though extension of the stimulated lower limb was evoked by scratching the skin or by pinching the tissues just above the knee, and was accompanied by a less vigorous contraction of the extensors of the opposite limb, erection of the penis did not occur, nor was contraction of the abdominal muscles obtained as a rule. Sometimes, however, the lower part of the ipsilateral half of the abdomen contracted slightly. The threshold value of the stimulus was lowest in the penis and there a rubbing stimulus was alone adequate. Nocuous stimulation of the glans, as pinching or pricking, inhibited the reflex. Handling the scrotum evoked a response, and firm rubbing was an adequate stimulus when applied to the pubis or the upper part of the inner surface of the thighs. In the outer portion of the field, however, nocuous stimulation was necessary to elicit the response. The threshold increased gradually towards the periphery of the reflexogenous area. By moving the prepuce backwards and forwards over the glans the reflex was evoked with greatest ease and it was seen in its most complete form. It could be evoked only imperfectly when the penis was flaccid.

(2) The motor response: When the glans was stimulated the penis became turgid. Then as the prepuce was drawn forwards the organ was felt to stiffen still more and simultaneously the testicles and scrotum retracted. The abdominal wall, chiefly its middle part corresponding to the recti, contracted sharply, so that the wall became flat, and the flanks "bagged" somewhat. The abdominal response involved principally the lower half or three-quarters of the wall. At the same time both lower limbs became rigidly extended with the feet and toes pointing. The response was bilaterally symmetrical. If it was evoked from a part of the receptive field situated to one side of the middle-line the response was more vigorous on the ipsilateral side. Thus when the locus of the stimulus was in the right groin the extensors of the right lower extremity reacted more than did those of the left lower limb and the abdominal response was likewise unequal. The asymmetry of the reflex became less as the stimulus was applied nearer to the middle-line. The response was quick and not appreciably delayed and it lasted as long as the brief stimulus was applied. If, however, the stimulus was prolonged the response usually failed after a short time.

March 29 (178 *Days after the Injury*).

Reflexes : Extension movements of the lower extremities occurred when the light pressure was applied to the sole. If with the limb resting on the bed in the position of flexion, the front part of the sole was gently pressed with the thumb so as to put the calf muscles on the stretch, an extensor thrust of the leg was evoked. The response consisted of extension at the knee, plantar extension of the foot and downgoing toes. The reflex, which was often followed by flexion, could be elicited when the limb was only slightly flexed. If the foot was pushed up too quickly a clonus of the calf muscles followed. The reflex was obtained in both lower limbs, but was more vigorous in the right.

I was not satisfied on this occasion that crossed flexion accompanied the response, though it had been definitely obtained at other times. The receptive field for this reflex was limited strictly to the sole of the foot, and the focal area seemed to be over the heads of the metatarsal bones.

The condition of the sphincter ani.—As the finger-tip touched the anus, the sphincter contracted so that the skin wrinkled. This continued till the finger had penetrated the canal. Then slight but distinct relaxation occurred. As the finger was allowed to rest in the canal the muscle held it with a slight steady tonic contraction. One had the feeling that the sphincter had taken up a new posture to accommodate the contents of the canal.

Reflex evacuation of the rectum.—Like the bladder the rectum evacuated its contents automatically. The amount of fluid forming the adequate stimulus varied with the quantity of fæcal matter in the rectum. It ranged from 100 c.c. to 300 c.c. When evacuation occurred the sphincter relaxed, and the detrusor threw out its contents by vigorous contraction. Passive dribbling was unknown. Sometimes the fluid and fæces were voided in two or three discharges.

The following observations on the *activity of the bladder* were made with Dr. Head on this day :—

On cleansing the glans, erection of the penis was evoked. No evacuation occurred. A catheter was passed and 280 c.c. of urine was drawn off. Fluid was poured into the bladder through a burette inserted in the catheter. At 280 c.c. the fluid was held for some time, but at 295 c.c. evacuation occurred ; 290 c.c. voided. The stream was rhythmic. By pressing deeply into the hypogastrium about 7 c.c. were recovered in addition. Fluid was again poured into the bladder and there was long delay at 320 cc. Evacuated at 350 c.c. Passed 330 c.c. By pressure 20 c.c. Fluid inserted and sole was rhythmically scratched, so as to induce flexion reflexes. Backflow occurred when the bladder contained 275 c.c. Evacuated 270 c.c. By pressure 10 c.c. Fluid again allowed to flow into the bladder. Rhythmic scratching of the sole, right and left. Evacuated at 285 c.c. Passed 280 c.c. By pressure 10 c.c. Fluid again poured in. Patient asked to take a deep breath at intervals. Evacuated at 260 c.c. Passed 230 c.c. By pressure, 30 c.c.

These observations show that bladder activity was not facilitated by extra-vesical stimulation.

Condition on September 8 (310 Days after the Injury).

Motion.—Total paralysis of lower extremities and of trunk below the sixth rib. Spontaneous movements of the legs were not vigorous. They were invariably steppage movements consisting of dorsiflexion of one foot with plantar extension of the other. The limbs lay extended on the bed with the toes in line with the feet or, if anything, a little "flexed."

Reflexes.—Ipsilateral flexion evoked by scratching the sole was accompanied by contralateral extension. The receptive field for the reflex reached to the junction of the upper and middle thirds of the leg. The threshold was lowest in the sole. Excitation of the outer edge of the foot gave dorsiflexion with eversion of the foot, while from the inner edge of the sole dorsiflexion with inversion was obtained. From the upper third of the leg to the top of the thigh, the groin and perineum a bilateral extension reflex was evoked, more vigorous on the stimulated side. It was symmetrical when excited from the middle-line. Its focal area was round the external genitals and in the perineum. An extensor thrust was readily obtained from both lower limbs. Knee- and ankle-jerks were brisk, right and left. Each response consisted of a quick rise and a slow fall away. Ankle clonus was not obtained on this date.

Cremasteric, bulbo-cavernosus and complete coitus reflexes were very brisk. On scratching the right or left half of the abdomen, a beautiful local reflex contraction of the external oblique was evoked. A general contraction of the rectus abdominis followed excitation of the skin in the middle-line. If the stimulus was applied over the rectus to the right or left of the middle-line, one rectus alone contracted as a rule.

Sensation.—Complete loss of touch and pain below the sixth rib. Neither vibration of large tuning-fork (C = 128) nor pressure with the algometer caused any form of sensation below and including the pelvis. The lower extremities have always seemed to the patient to be lying stretched out in front of him.

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STUDIES ON THE DIFFERENT REACTIONS (LYMPHOCYTOSIS, BISGAARD, ROSS AND JONES AND WASSERMANN) IN THE CEREBROSPINAL FLUID IN CASES OF SYPHILIS.[1]

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In working through this material my chief object has been to show that in the test first described by Ross and Jones, and later modified by Bisgaard, we have an easy and reliable method for estimating qualitatively and quantitatively the globulin and albumin fractions of the proteid in the cerebrospinal fluid.

The greater number of my cases were patients in the dermatological department of the Rigshospital; some, however, belonged to other departments of this hospital, more especially to the medical departments A and B. The number of cases, especially in the early stages of syphilis, compares favourably with those previously published by other authors; moreover I have had the opportunity of examining the influence of treatment with mercury and salvarsan, both in early and in late stages of syphilis, upon the different reactions in the cerebrospinal fluid, and I hope that the deductions arrived at concerning not only the Bisgaard-Ross-Jones reaction (B.R.J.) but also the cell-count and Wassermann reaction (W.R.Sp.) in the cerebrospinal fluid may prove of some interest.

To the head of the Dermatological Department, Professor Dr. C. Rasch, I am indebted both for allowing me to work through the material in his department and also for his continued interest in my studies. To Professors Faber and Gram and the heads of several of the other departments of the Rigshospital, who have sent to me for examination specimens of cerebrospinal fluid, and to Dr. Axel Reyn (the head of the Cutaneous Department of Finsen's "Lysinstitut"), for permission to

[1] This paper was sent to the Editor and accepted in April, 1916. It required verbal alterations, which were not completed till 1917. Then communication with Denmark became so difficult that the final proof was not completed in time for the issue of Vol. xl, Part 1, in May, 1917. It has therefore been dated June, 1917.

apply intrathecal injections of neosalvarsan in a case of dementia paralytica, I tender my best thanks.

I am also much indebted to Dr. Fearnsides, who has kindly revised this paper for publication in English.

In the great majority of cases I have myself counted the cells and carried on the examination of the proteids, but the Wassermann reactions in the cerebrospinal fluid have been estimated for me in the "Statens Serumsinstitut," usually by Drs. Thomsen and Boas.

In this paper I have laid little stress upon the appearance of the Wassermann reaction in the serum, partly because in a previous paper written with H. Bang I have dealt with this subject, and partly because the bearings of this reaction in the serum upon affections of the central nervous system have been discussed by several other authors. Most neurologists seem inclined to attach undue importance to the presence of this reaction in the serum by regarding it as one of "Nonne's four reactions." The finding of a positive Wassermann reaction in the serum (W.R.Ser.+) gives us the important information that the patient is syphilitic, but does not tell us whether the given lesion in the brain or spinal cord is syphilitic or not. On the other hand, most authors are agreed that the finding of a positive Wassermann reaction in the cerebrospinal fluid (W.R.Sp.+)[1] indicates a lesion of the central nervous system. In the early years after the appearance of Wassermann and Plaut's work positive reactions in the cerebrospinal fluid were comparatively rarely obtained because in the test the authors employed too small a quantity of cerebrospinal fluid. In later years it has been realized that it is possible to get a greater number of positive reactions without the risk of getting "non-specific reactions" by using a larger quantity of cerebrospinal fluid. Thomsen and Boas use as much as 1·2 c.c. or 1·0 c.c. of *heated* cerebrospinal fluid and employ as antigen an alcoholic extract of human heart. Fildes and McIntosh "have always used a maximum of 0·2 c.c. in a volume of 1·0 c.c." but, probably due to their use of *unheated* cerebrospinal fluid and heart-cholesterin antigen, their results are just as reliable. In a later chapter I have dealt with some of the drawbacks of using the unheated fluid.

[1] In this paper when I use the term *W.R.Sp.* −, it signifies that the Wassermann reaction in the cerebrospinal fluid is negative with 1·0 c.c. of the heated fluid, and when the term *W.R.Sp.* + is employed, I always add, in a bracket, the quantity of cerebrospinal fluid with which the reaction has been found positive and a figure indicating the degree of hæmolysis; thus the figure 0 indicates complete inhibition of hæmolysis, whilst the number 100 indicates complete hæmolysis.

In this paper I shall not discuss the methods of estimating the number of cells in the cerebrospinal fluid nor attempt to evaluate the respective methods. In my own work I have always used the Fuchs-Rosenthal chamber and have usually counted the cells immediately after lumbar puncture. I have preferred this method, both because it is simple and because also it seems to have been the one which has been most widely employed, and so allows of a comparison of my results with those obtained by other authors. I am well aware of the drawbacks to the method, but after due consideration these drawbacks do not seem to be greater than those met with in the methods based upon counting the cells in the deposit after centrifugalization. In the Fuchs-Rosenthal chamber it may be difficult to differentiate between erythrocytes and leucocytes, and it is usually impossible to distinguish the different kinds of leucocytes.

Donald's method of counting the number of cells present in a small drop of known capacity is based upon a new principle and looks promising (Fildes and McIntosh [26]), but so far I have had no experience of the method.

In the papers by Bisgaard, Boyd, Ross and Jones, Turner and Zaloziecki, will be found a discussion upon the relative values of the various proteid reactions, and on this subject I shall not enter further.

Starting from the observation that the "globulin fraction" (phase 1) of the proteids in the cerebrospinal fluid is precipitated by the addition of the same amount of a saturated solution of neutral ammonium sulphate, Nonne and Apelt [48] found that the cerebrospinal fluid of a patient suffering from a syphilitic lesion of the central nervous system showed a more or less distinct turbidity ("Trübung") when it was mixed with an equal quantity of the solution of ammonium sulphate. This turbidity, "the phase 1 reaction," was not found in patients suffering from other diseases. The results obtained by these two authors were apparently so satisfactory that they did not take much interest either in the fraction of proteid which was not precipitated by ammonium sulphate (phase 2), or in the total amount of proteid. Whilst many authors were satisfied with the Nonne-Apelt reaction and the later modifications of this ammonium sulphate method, or with the somewhat more elaborate butyric acid test of Noguchi; others with more or less success tried to find a practical method for the determination of the total proteid. Improvements in the technique of the Nonne-Apelt test were described by Ross and Jones and by Boyd. Zaloziecki, on the other hand, attempted to determine the best method of estimating the

nitric acid fraction, whilst Bisgaard discovered a method of estimating both fractions quantitatively.

Ross and Jones [54] first described a method of observing the "globulin reaction" as a ring at the junction of the two fluids. "In the Ross-Jones reaction 1 c.c. of cerebrospinal fluid is run on to the surface of 2 c.c. of a saturated solution of neutral ammonium sulphate. A positive reaction is indicated by the appearance of a ring at the junction of the two fluids, a ring which ought to be clear cut and of the thickness of a sheet of paper" (Boyd [24]). The ring should form within three minutes. Indirect illumination and a dark background must be used, or the faintest ring may escape detection. The strength of the reaction is estimated by the thickness of the disc, by the rate at which it appears, and the dilution of the cerebrospinal fluid with which it may still be obtained. Unfortunately these two authors only examined comparatively few cases and left to their successors the work of carrying out their suggestions for a quantitative test. Their method was later recommended by Amsden [3], who used it with fairly consistent results in a few cases, and by Turner [57], who obtained comparable results in forty-eight cases of dementia paralytica and in forty-five control cases.

A quantitative method based upon the Ross-Jones technique was first worked out by Boyd [24]. He writes, p. 218: "In order to make the test a quantitative as well as a qualitative one the fluid was diluted, and that degree of dilution noted with which the ring could just be obtained." He found that when the method was applied to the fluid obtained from the same case on a number of different occasions the results were remarkably uniform. In contrast to Ross and Jones, and Bisgaard, Boyd allowed a period of five minutes to elapse before he regarded a given reaction as a negative one. Thus he obtained somewhat higher values than Bisgaard and the present author, and this difference must be taken into consideration when comparing results. Provided that the ring be not obtained when the fluid is diluted, he does not regard the appearance of a ring at the end of five minutes as a pathological sign. Boyd examined eighty-seven specimens of cerebrospinal fluid; in forty-one cases the reaction was negative, and in forty-six positive; in twenty-six cases a ring was only obtained with undiluted fluid, in eight cases the ring was still visible in the dilution of one in two (of these eight cases one was an example of dementia paralytica), and in twelve cases the reaction was positive in a still higher dilution. Boyd accordingly regarded the appearance of a ring in a dilution of

one in two as pathological. On the other hand, the results obtained by Bisgaard and myself upon a larger material do not support this view.

Bisgaard [12], who had not read the paper by Ross and Jones, later published a quantitative and qualitative method for determining the globulin fraction practically identical with the one just described, and in the same paper described a method for the quantitative estimation of the amount of proteid which had first been employed for testing urine.

Zaloziecki [63], using like the English authors a black box and indirect illumination, first employed this method to the investigation of specimens of cerebrospinal fluid.[1]

Bisgaard and other authors have shown that Nonne's original technique is very insufficient and that in the decision as to whether a doubtful reaction ought to be regarded as positive or negative too much depends upon the bias and individual experience of the observer; in Bisgaard's method the results are recorded as a number the value of which is easily appreciated. Nevertheless in a given case it may be difficult to say whether the reaction ought to be regarded as positive or negative, because an "ammonium sulphate fraction" is often found even in specimens of "normal" cerebrospinal fluid and all stages of transition between normal and pathological fluids occur. Zaloziecki [63], like Bisgaard, has criticized Nonne-Apelt's method in an interestng paper; he, however, thinks that Bisgaard's method possesses the same drawbacks as the original and that, therefore, Bisgaard's results, despite his large material, have only a minor value. Zaloziecki as his main conclusion states that "jeder Liquor mit Globulinvermehrung gleichseitig auch bei der Bestimmung der Gesamteiweisses eine deutliche Zunahme zeigen muss" and "dass bei jeder stärkeren Eiweissvermehrung auch positive Globulinreaktionen zu erwarten sein werden, dass aber ein negativer Ausfall dieser letzeren noch nicht eine mässige Eiweissvermehrung ausschliesst." Zaloziecki summarizes his opinion of the clinical value of an augmentation of the "globulin fraction" in the statement that "a positive phase 1 (Nonne-Apelt) indicates an augmentation of proteids from a half to several per thousand, but is no direct expression of the amount. It has at present no other clinical importance."

[1] Throughout this paper I have used the term Bisgaard-Ross-Jones reaction (B.R.J.) to signify this proteid reaction; Ross and Jones first described the technique, but it was Bisgaard who first applied the technique to the investigation of any considerable material. For the "nitric acid fraction" Bisgaard [17] found an average error of 2·71 per cent. and for the "ammonium sulphate fraction" an average error of 4·83 per cent.

The "physiological values" of the ammonium sulphate reaction, according to Bisgaard, lie between 0 and 2, and those of the nitric acid reaction lie between 6 and 20, and according to Zaloziecki a reaction with nitric acid in a dilution of 20 must be regarded as pathological. As the results of numerous investigations Bisgaard draws the following conclusions ([17] p. 122): "The proteids of phase 1 have qualities in common with the globulin of serum, whilst the proteids of phase 2 have properties in common with serum albumin. In phase 1, however, some proteids of lower molecular weight are precipitated." Thus we are bound to admit that the mere investigation of the "globulin" and "albumin" fractions of the cerebrospinal fluid gives some impression of the complicated chemistry of the heterogeneous collection of proteids present in this fluid, and that before we can make any definite statements concerning the clinical value of the presence of each fraction many observations on numerous cases are needed. The results obtained from investigations on Bisgaard's and my own material seem to me to prove that Zaloziecki's conclusions are wrong. His first statement that an increase in the amount of globulin is always accompanied by an increased value of albumin is negatived by values like (3-15) and (4-15) in Bisgaard's cases of dementia paralytica and by my own findings of (6-15) in Case 25, (4-10) in Case 37, (3-10) in Case 48, (5-15) in Case 90, (4·5-15) in Case 91, (3-12) in Case 118 and (5-15) in Case 124. His last conclusion that a negative "globulin reaction" does not exclude a pathological increase in the "nitric acid fraction" is supported by a value like (1-50) in one of Bisgaard's cases of tuberculous meningitis, and in a less degree by values like (2-32·5) and (2-30) in my Case 12.

The two reactions are supplementary, and seeing that both are easily tested and the average error is comparatively trifling, both ought to be used in the clinic.

Seeing that cerebrospinal fluids with abnormal cell-counts and even showing a positive Wassermann reaction, but giving normal proteid values, are occasionally found, it is probable that in pathological cases proteids which are not detected by any of the above-mentioned methods are present. Lange [37, 38] and several other authors have proved that proteids exist which precipitate a colloidal suspension of gold and that the Wassermann bodies probably are connected with these substances.

A few words as to actual procedure may be useful. Personally, I always use the black box described by Bisgaard and made for me by Camillus Nyrop. To sharpen the sight the transverse slit in front is mounted with a funnel-shaped tube. At a fixed distance above the

opening at the top an electric lamp is placed. The whole apparatus is fixed on to a foot the height of which can be adjusted. A piece of black cloth is indispensable. Some pipettes and a number of glass tubes 130 mm. long and 10 mm. broad are needed. I always use 1 c.c. of the diluted cerebrospinal fluid and 1 c.c. of the reagent. The reagent is always run to the bottom of the diluted fluid by means of a Pasteur's pipette. If no disc appears at the junction of the two fluids after the lapse of three minutes the reaction is regarded as negative with the given dilution. The cerebrospinal fluid should always be diluted with a solution of pure NaCl (0·9 per cent.). The nitric acid should have a specific gravity of 1·18. The solution of ammonium sulphate must be completely saturated and should have a neutral reaction. I shake 80 grm. of chemically pure $(NH_4)_2, SO_4$ with 100 grm. of water, and warm to 70° C. for about half an hour. During the testing the pipettes for the two reagents must be kept separate. I have always preferred to read the reactions by night, as without further precautions daylight is rather disturbing. After some experience I find that each reaction takes about fifteen minutes. Time is generally saved if we start by preparing a standard dilution of the cerebrospinal fluid of one in ten: this dilution may be used for the nitric acid test. If the nitric acid test is just positive we get "phase 2" equals 10. If a ring is just obtained after three minutes in the ammonium sulphate test, "phase 1" equals 1. B.R.J. would then be recorded as (1-10). B.R.J. (5-25) signifies that the ammonium sulphate reaction is obtained in a dilution 1 in 5, and the nitric acid reaction in 1 in 25. The original Nonne-Apelt reaction in a given dilution may be obtained by shaking the tubes and then observing the degree of turbidity after the lapse of three minutes.

Chapter I.—The Different Reactions in Control Cases.

Before attempting to discuss the diagnostic value of the different reactions in the cerebrospinal fluid in cases of syphilis, it is necessary to have examined a considerable number of control cases, but owing to the fact that lumbar puncture is a somewhat painful procedure and its after-effects may be unpleasant, control cases in large numbers are difficult to obtain.

(1) *The Cell-count.*

Numerous authors have dealt with the cytology of normal cerebrospinal fluid, but owing to the differences in technique the results obtained by these are not all directly comparable. The French school,

following Ravaut [51], count the number of cells obtained in the deposit after centrifugalization. Ravaut regards as a "réaction nulle" 0-3 cells "par champ d'objectif à immersion" and as "réaction discrète" 4-6 cells. Fuchs and Rosenthal, employing a counting chamber invented by themselves, have found as normal 0-2 cells per cubic millimetre, Rehm found 1-5 and even 6-9 cells, and Gennerich [30] once found in a healthy person as many as 8 cells per cubic millimetre. Fortunately, however, the figures given by different authors do not vary much, and I think we may safely regard a cell count of 4 or *less* than 4 as normal, and a count between 4 and 10 as suspicious of a pathological process, and a cell-count greater than 10 as definitely pathological.

I have personally examined the cerebrospinal fluid in forty-four patients (twenty-eight men and sixteen women) in whom there was no reason clinically to expect any gross alterations in the cerebrospinal fluid. In Table I are given the number of patients and the diseases from which they were suffering; if the cell count or B.R.J. results were not precisely normal I have added the value in brackets.

TABLE I.

Balanoposthitis	1 male.
Herpes genitalium	1 female.
Gonorrhœa	5 males [B.R.J. 0-20].
,, ...	2 females [L. 7, B.R.J. 1-10].
Venereal sore	2 males [L. 11·3, B.R.J. 1·5-15; L. 3·7, B.R.J. 0-10].
.. ,, ...	2 females [L. 1, B.R.J. 1-25; L. 2·3, B.R.J. 2-10].
Phagedæna penis	2 males [L. 4].
Lepra	1 male.
Lichen ruber	1 male.
Lupus facialis	1 female.
Lupus erythematosus ..	2 females [B.R.J. 1·5-15].
Dermatitis herpetiformis ..	1 male [L. 1, B.R.J. 1-20].
Epidermolysis traumatica ..	1 male [L. 2·3, B.R.J. 1-18].
Prurigo	1 male and 1 female.
Pruritus	1 male.
Ulcer of the thigh	2 males [L. 11·3, B.R.J. 1·5-15].
Malignant lymphomata ..	1 male.
Dystrophia adiposo-genitalis	1 female.
Mental depression	1 male [L. 1, B.R.J. 1-20].
Epileptic insanity	1 male.
Cerebral abscess	1 female.
Spastic paraplegia	1 male [L. 3, B.R.J. 1·5-20].
Disseminated sclerosis ..	3 males [L. 2·3, B.R.J. 2-15; L. 2·7, B.R.J. 1·5-15; L. 1, B.R.J. 2·5-25].
,, ,, ..	3 females [L. 0·7, B.R.J. 0-12; L. 3·3, B.R.J. 15-18; L. 0, B.R.J. 0-10].
Syringomyelia	1 female [L. 1, B.R.J. 2-20].
Iridocyclitis	1 male.

In fourteen specimens only was the number of cells greater than 2 per cubic centimetre; 2·3 lymphocytes per cubic millimetre were observed in four cases, 2·7 in one case, 3 in four cases, 3·3 in one case, and 3·7 in one case respectively; 4 lymphocytes per cubic millimetre were found in a young man with gangrene of the penis: 7 lymphocytes per cubic millimetre were found in one case of a female suffering from gonorrhœa but showing no evidence of syphilis. Such a number is not necessarily pathological but should be an indication for continued observation and renewed lumbar puncture. A similar observation applies even more forcibly to the case of a male suffering from ulcus penis (without spirochætes) and adenitis inguinalis dextra, in whose serum the Herman and Perutz and the Wassermann reactions were all negative, but in whose cerebrospinal fluid 11·3 lymphocytes per cubic millimetre were counted and the B.R.J. reaction was (1·5-15). In such a case, as will be realized from the later discussion, it would be inadvisable to exclude syphilis completely.

Seeing that the number of non-syphilitic controls is comparatively small, it may be of interest to state the number of cases of syphilis in whom no nervous manifestations were discovered and at the same time in whose cerebrospinal fluid 10 or fewer cells per cubic millimetre were counted. Amongst 439 cases, in 183 the cell-count numbered from 0-1 cells, in 104 from 1-2, in fifty-six from 2-3, in forty-six 3-4, and in fifty cases 4-10. Thus only in fifty cases out of 439 (11·3 per cent) was a cell count of 4-10 found: accordingly the finding of more than 4 cells per cubic millimetre should always be viewed with suspicion.

(2) *The Bisgaard-Ross-Jones Reaction.*

As comparatively few control cases upon this reaction have been published, I give in the following a *résumé* of the literature upon this reaction.

Ross and Jones [54] examined twelve control cases and found none which gave a positive reaction. Turner [57] in twelve cases of dementia præcox, in eight cases of epilepsy and in eighteen unclassified cases found the reaction negative. Boyd [24] examined the globulin fraction in seventy-five control cases. The result was negative in forty cases; twenty-six gave a ring with undiluted fluid and seven still showed a positive reaction in the dilution of 1 in 2; in one case of acute mania and in another of dementia præcox the reaction was positive in a dilution of "1 in 4-6." Boyd regarded all cases showing a positive

reaction after dilution as pathological. The observations of Bisgaard, which I have confirmed, show that as far as the dilution 1 in 2 is concerned this statement is not correct. Boyd's specimens showing negative or positive fraction reactions were obtained from eleven cases of acute mania, two of alcoholic excitement, (1) two of confusional insanity, fourteen (1)[1] of congenital imbecility, five of chronic mania, one of chronic rheumatism, nine of dementia præcox, one of diabetes, one of folie circulaire, fourteen (4) of epilepsy, five (1) of melancholia, one of paranoia, one of pharyngitis, four of secondary dementia, two of stuporose insanity. His two patients with high globulin fractions showed in addition a well-marked ammonium sulphate reaction and also a considerable degree of lymphocytosis, but as the Wassermann reaction in the cerebrospinal fluid was not tested in these two cases, I think it is impossible to exclude syphilis.

Bisgaard [17] has examined fifty-two control cases; of these forty had a globulin value of one or lower than one and the nitric acid values about fifteen or less; in twelve cases the values of both were greater. His cases, with the figures when abnormal stated in brackets, are as follows:—

Congenital imbecility	2.
Dementia alcoholica	14 (0·20, 1·20, 1·22·5, 3·20).
,, arterio-sclerotica	6 (1·20, 3·20).
,, præcox	11 (0·18, 1·18).
,, senilis	1 (1·20).
Folie circulaire	1.
Emollitio cerebri	4 (1·25).
Epilepsy	5.
Hysteria	1 (2·20).
Suppurative mastoiditis	1.
Meningeal irritation	1 (2·11).
Croupous pneumonia	3.
Disseminated sclerosis	1 (4 cells, 1·17).
Septicæmia	1.

The value (3·20) was found in an old prostitute with dementia alcoholica, and the same readings were obtained in one male with dementia arterio-sclerotica, a disease in which other authors have found an increase in the proteid content of the cerebrospinal fluid such as occurs in uræmia.

I have examined personally forty-four cases; in Table I the diagnosis of these cases is given. Fifteen of these patients showed a value greater than *one* for the "globulin" fraction and greater than *fifteen* for the "albumin" fraction. B.R.J. (0·20) occurred in

[1] The numbers added in brackets show the number of cases of extra positive reactions in the following condition obtained with the dilution 1 in 2.

one case, (1-20) in two, (1-25) in one, (1·5-15) in four cases, (1·5-20) in two, (2-10) in one, (2-15) in two, (2-20) in one and the value (2·5-25) was found in a single instance.

Only a few of these values need particular comment. B.R.J. (1-25) and (2-10) were observed in two females, both showing venereal ulcers, and possibly either or both patients may have been syphilitic. The only disease in which a definitely pathological value (2·5-25) was obtained, was disseminated sclerosis, and from Table I, p. 410, it will be readily seen that the proteid values in this disease are often rather high, a fact which previous authors have recorded; in disseminated sclerosis a slight degree of pleocytosis may be present as well as this increase in proteid content.

As a second kind of "control" case may be taken the value of the B.R.J. in patients suffering from a syphilitic affection and no nervous manifestations. An ammonium sulphate fraction between 0 and 1 and a nitric acid fraction between 8 and 15 were found in 326 out of 401 cases. Table II shows the frequency at which the different values of B.R.J. occurred in this series of cases of syphilitic disease.

TABLE II.

Values of B.R.J.	0-10	0-15	0-20	1-10	1-15	1-20	1·5-10	1·5-15	1·5-20	2-10	2-15	2-20	1-25	1·5-25
Number of cases	189	53	14	52	32	15	5	8	6	3	7	12	3	2

If we exclude patients suffering from dementia arterio-sclerotica and disseminated sclerosis we arrive at the result that a material of about 150 "control" cases showed an ammonium sulphate value generally one or less, but sometimes as great as two: the nitric acid value is generally fifteen or less, fairly often twenty, and in a few instances twenty-five.

(3) *The Wassermann Reaction.*

Fildes and McIntosh [26] obtained a negative Wassermann reaction in the cerebrospinal fluid in forty-four non-syphilitic control cases. Boas and Neve [22] examined seventy control cases without obtaining a single positive reaction in the fluid, though they used quantities up to 1·0 c.c. A negative reaction was found in the forty-four control cases detailed on Table I, in one case of erythrodermia exfoliativa and in seventeen of my cases of cerebral or spinal tumour. If my sixty-

two and Boas and Neve's seventy cases are taken together we get 132 negative reactions in the cerebrospinal fluid of non-syphilitic patients as investigated with the technique of the "Statens Serum-institut," using up to 1·0 c.c. of the spinal fluid.

Chapter II.—The Reactions in Cases of Cerebral and Spinal Tumours.

Most authors are agreed that a positive Wassermann reaction is never found in the cerebrospinal fluid of a patient suffering from a non-syphilitic tumour of the spinal cord or brain and that in such cases pleocytosis is rare, but statements concerning the proteid content of the cerebrospinal fluid are more at variance. Nonne's rule is that his "phase 1" may occur, but is generally slight. Bisgaard examined the proteid content in two cases of cerebral tumour: Of these one gave the B.R.J. (2-30), and the other the high value of (8-120). Borberg [23] in 1915, before the Neurological Society of Copenhagen, demonstrated a case suffering from a tumour of the spinal cord whose cerebrospinal fluid showed a B.R.J. of (5-250), but no increase in the cellular count.

My own material of twenty-four cases includes five in which the diagnosis was not quite certain (Cases 20-24 of Table III). In thirteen out of the twenty-four the cerebrospinal fluid contained a normal *amount of proteid* and showed no alterations in the cellular count. In Case 7 unfortunately the fluid was contaminated with blood. In four cases (Cases 15, 19, 21 and 22) the proteid-content was slightly increased, the globulin-fraction reaching values like three, and the albumin-fraction values as high as thirty. In six cases (Cases 5, 6, 10, 11, 23 and 24) the proteid-content was considerably increased, and in the majority of cases, especially those showing the highest total values, the globulin-fraction was relatively increased most. Values of B.R.J. like (14·5-75) and (9-75) which Bisgaard formerly regarded as characterizing the fluid obtained from cases of dementia paralytica only, but which are now known to be found equally in some other forms of syphilitic disease of the nervous system, indicate that the differences between the cerebrospinal fluid obtained by puncture of cases of tumour and of syphilitic diseases are less distinctive than most previous authors had thought.

My own observations confirm the general view that *lymphocytosis* is rare in cases of cerebral tumour and of spinal tumour. In

TABLE III.

o.	Sex	Age	Diagnosis	Wassermann Reaction.		Number of cells per c.mm.	B.R.J.	
				Serum	Cerebro-spinal fluid			
1	F.	37	Cystis cerebri hemisphæræ (glioma)	–	–	1·3	1·5—10	
2	F.	c. 40	Tumor cerebelli hemisphæræ, puncture, 31/10	..	–	0·7	1—10	Autopsy.
			„ 10/11	..	..	0·7	1—10	
3	F.	c. 30	Tumor cerebri (chiasma nerv. opticorum). Pachymeningitis chron. Erysipelas	..	..	0·7	1—15	Autopsy.
4	M.	33	Tumor cerebelli (glioma). About ten years ago eruption of syphilis, and then treated with inunctions	–	–	2·7	0—15	Autopsy.
5	F.	19	Sarcoma cerebri hemisphæræ	..	..	1	4—40	Autopsy.
6	M.	53	Tumor medullæ cervicalis (sarcoma)	–	–	3	9—75	Autopsy.
7	F.	25	Tumor medullæ	–	–	8	4·5—25	Autopsy. The cerebrospinal fluid was blood-stained
8	M.	16	Cystis cerebri. Leptomeningitis chron. Sequelæ encephalitidis	–	..	1	0—9	Operation.
9	M.	26	Tumor medullæ spinalis ..	–	–	–	1·5—22	
10	M.	46	Tumor acusticus (fibro-sarcoma)	..	–	0	4—35	Operation.
11	F.	35	Tumor acusticus (glioma) ..	–	–	0·3	14·5—75	Operation.
12	M.	15	Tumor pontis vel cerebelli ..	–	–	0·7	2—20	
13	M.	64	Tumor cerebri (chiasmatis) ..	–	–	1·3	1—18	
14	F.	40	Tumor intraspinalis regionis dorsi	–	–	0·7	0—14	
15	F.	49	Tumor cerebelli	–	–	1	2—30	
16	M.	c. 25	Tumor spinalis	..	–	2·3	2—20	
17	F.	50	Tumor cerebelli	–	..	0	0—10	
18	M.	29	Tumor cerebello-pontis ..	–	..	0	0—8	
19	M.	11	Tumor acusticus	..	–	2·3	3—20	
20	F.	37	Observation for tumor cerebri. Infected with syphilis eight years ago, and then treated with inunctions	–	–	0·3	1—10	
21	F.	68	Observation for tumor cerebelli	..	..	0	2·5—25	
22	F.	36	Observation for tumor cerebri	–	–	3·7	2·25	
23	F.	25	Observation for tumor cerebri	–	–	6·7	3·50	
24	F.	22	Observation for tumor cerebri. Sequelæ cortus caputis	..	..	1	4—25	Cerebrospinal fluid yellowish.
25	M.	6	Tuberculoma cerebri	..	–	2	2·5—20	
26	F.	61	Myelitis transverse in spondylitide (tuberculosa)	–	–	1·3	15—15	
27	M.	48	Meningitis chronica	–	–	0·3	2—25	Autopsy.
28	F.	38	Argyll Robertson's symptom. Polyneuritis, puncture 22/3	–	–	0	10—80	
			puncture 22/4	..	–	3	15—400	

In addition to these twenty-four cases of tumours of the central nervous system I have examined four other non-syphilitic specimens of cerebrospinal fluid which showed pathological changes in the proteid-content, and these I have appended at the foot of Table III. Case 28 possesses some interest. This patient showed a series of nervous signs and symptoms leading to a diagnosis of "polyneuritis," and in addition showed the Argyll-Robertson phenomena, but no etiological cause of the polyneuritis was discovered. The B.R.J. reaction (10—80) and the reaction of the pupils suggested a diagnosis of syphilis, but the finding of a negative Wassermann reaction in the serum and in the cerebrospinal fluid, and no lymphocytosis after inefficient treatment with inunctions of mercury, do not favour this diagnosis. In this case after twenty inunctions with mercury during four weeks, the B.R.J. became (15—400), a value which is not suggestive of syphilis as the etiological cause.

eighteen patients, in whom the diagnosis was certain, the highest cell-count was 3 per cubic centimetre, and even if the five patients in whom the diagnosis was somewhat doubtful be all included the highest value is 6·7 per cubic centimetre (Case 23). Thus amongst twenty-three cases a definite lymphocytosis was never found. The finding of a pathological value of B.R.J. in the absence of any increase in the cellular count is comparatively rare in syphilis, hence the absence of lymphocytosis in a specimen of cerebrospinal fluid which contains an increased amount of proteid has some diagnostic value.

The material through which I have worked is too small to allow any definite statement upon the reactions in different forms of cerebral and spinal tumours, but in Table III I have given the diagnosis and the values of the reactions in all my cases, in the hope that others in the future may be able to make use of these observations.

Chapter III.—Reactions in Syphilis.

(1) *The Reactions in Patients suffering from Primary Syphilis but giving a Negative Wassermann Reaction in the Serum.*

I have examined the cerebrospinal fluid from forty-five patients suffering from either a primary syphilitic sore or from a syphilitic bubo who showed neither cutaneous manifestations nor gave a positive Wassermann reaction in the serum. In three cases only (Cases 4, 5 and 6) were definite pathological changes in the fluid present, and in two further cases the fluid was normal except for a small increase (up to six cells per cubic millimetre) of the cellular content—i.e., in 93·6 per cent. of these cases the cerebrospinal fluid was practically normal.

My material is too small to allow me to form any definite judgment upon the alleged power of salvarsan to provoke the various reactions in the cerebrospinal fluid, nevertheless it struck me that several of my cases gave evidence of such an effect.

Case 5 showed the unique coincidence of a negative Wassermann reaction in the serum (W.R.Ser. −), no excess of proteid or of cells, but a positive Wassermann reaction (W.R.Sp. + (1 c.c. −60)) in the cerebrospinal fluid. This case, like Case 3 whose cerebrospinal fluid contained 6·7 lymphocytes per cubic millimetre, had not been treated. In Case 6, the date of the infection was uncertain; here *before* any treatment was given the cerebrospinal fluid contained fourteen cells per cubic millimetre. This number increased *after* treatment with

mercury and two injections of salvarsan to 70 per cubic millimetre; after two additional injections of salvarsan the cell-count became practically normal. In two cases (2 and 4), both of which had been treated previously with salvarsan or neo-salvarsan, the cell-count was 6·7 per cubic millimetre, and in addition Case 4 showed the abnormal value of the B.R.J. of (2·5-35). Of the rest of the forty-five cases only three had been treated with salvarsan or neosalvarsan before the lumbar puncture. Case 1 has an especial interest.[1] A few days after the first injection of salvarsan this patient developed a paresis of his left abducens nerve. This paresis was possibly due to the toxic influence of the salvarsan (possibly local hæmorrhage) and not to any influence upon the latent syphilitic process. Two other cases a short time before examination had been injected respectively with 0·3 and 0·5 gramme of neosalvarsan. Three of six cases treated with salvarsan showed abnormalities of the cerebrospinal fluid. Of the remaining thirty-nine cases which before lumbar puncture had either received no treatment at all or a few inunctions of mercury only, two showed abnormalities of the cerebrospinal fluid. Thus, so far, Gennerich's [30] hypothesis, which will be discussed more fully later, is supported by my observations.

(2) *The Reactions in Patients suffering from Primary Syphilis and a Positive Wassermann Reaction in the Serum.*

I have examined thirty-seven cases of primary syphilis which showed no cutaneous manifestations but gave a positive Wassermann reaction. In three cases the cerebrospinal fluid showed definite pathological changes and in three additional cases doubtful alterations were present (i.e., in 91·9 per cent. of these cases the cerebrospinal fluid was normal). Three of these patients before lumbar puncture had received from two to eight inunctions of mercury. In one of these cases the cell-count was 4·7 cells per cubic millimetre and the B.R.J. (2-15), and in the second it was 6 cells per cubic millimetre with a B.R.J. of (1-20). In the third, Case 2, the cell-count was 10·3 cells per cubic millimetre. The three other patients showing abnormalities in the cerebrospinal fluid had been treated with salvarsan. In one case the patient had previously been treated with twenty-six inunctions of

[1] This case was demonstrated by Rasch at the Danish Dermatological Society on November 7, 1914. To the same Society I showed on February 7, 1917, a similar case which had not been treated with salvarsan; in this case, just as in the one quoted in the text, diplopia lasting about a week appeared ten days after a lumbar puncture. In this latter case, seeing that no other etiological factor could be found, it seems to me impossible to exclude the puncture as the cause of the phenomenon.

mercury and three injections of salvarsan (0·4, 0·5 and 0·5 gramme), and here the fluid contained 5·3 lymphocytes per cubic millimetre and a B.R.J. of (0—10). In the other two cases the increase in cells (twelve and twenty-one respectively) may have been related to treatment with salvarsan. In Case 10 the initial symptoms and the slow rate of decline in the cellular count after insufficient treatment make the case one of interest. As a contrast to these three cases three others had been treated before lumbar puncture with both mercury and salvarsan and yet showed no pathological changes in the cerebrospinal fluid. One of these patients was suffering from double optic neuritis, and yet both before and after intensive treatment with neosalvarsan the fluid showed no pathological changes.

Amongst the eighty-two cases of primary syphilis which I have examined, one of the reactions showed pathological changes in six cases (7·4 per cent.), and in eleven other cases the fluid was not quite normal (13·4 per cent.). Twelve of these eighty-two cases had been treated previously with salvarsan, and of these twelve cases in six the fluid was more or less pathological. On the other hand, in six out of seventy-two cases which had not been so treated similar pathological changes were present. These results, therefore, tend to support Gennerich's hypothesis, that salvarsan has a provocative influence upon changes in the cerebrospinal fluid in cases of primary syphilis.

Gennerich [30] examined the cerebrospinal fluid in thirty cases of primary syphilis, and in eight cases found either an increase in the cell-count or in the amount of proteid present. Altmann and Dreyfus [2] found pathological changes in the fluid in two out of eight cases, and Guttmann [32] found no changes in three cases. Ravaut occasionally found a meningeal reaction after an injection of salvarsan, but only "chez les malades dont le chancre est plus ancien." Boas and Neve [21] in nine cases of primary syphilis showing a negative Wassermann reaction in the serum found no alterations in the cerebrospinal fluid; once, on the other hand, amongst nine cases giving a positive Wassermann reaction in the serum they found eleven cells and a positive Weil-Kafka's hæmolysin reaction. In this connexion the finding by Boas of a positive Weil-Kafka reaction in one of my patients, a young man suffering from a primary sore on the lip and sub-maxillary adenitis where the Wassermann reaction in the serum was negative and the cerebrospinal fluid gave no other evidence of any pathological changes (cells 0·3 per cubic millimetre, B.R.J. (0-10), W.R.Sp.—(1·2 c.c.)) is interesting.

The finding of pathological changes in the fluid shows that a pathological process is at work in the meninges, and occasionally a clinically manifest meningitis may appear in the primary stage. Audry and Lavau [6] have described a fairly convincing case of this, and Lavau [40] has made mention of a patient showing a chancre, no skin eruption and a cerebrospinal fluid reacting positively to the Wassermann test and showing 15 cells per cubic millimetre but no increase in the proteid content.

(3) *Observations upon the Meaning of the Terms "Primary" and "Secondary" Syphilis and the Wassermann Reaction in Venereal Ulcers.*

In this paper, when I use the phrase "primary" syphilis with or without a positive Wassermann reaction in the serum, or "primary" syphilis in contrast to "secondary," it is not because of any undue respect for these somewhat misused terms, but because they have been once established and are fairly practical in their meaning.

As soon as a syphilitic rash and a chancre are observed together, no one disputes the statement that the infection is already generalized; but, as a rule, we are inclined to regard a chancre with an inguinal bubo and no skin-eruption as a rather localized process, and this more especially when the serum of the patient gives a negative Wassermann reaction. Modern authors, however, have pointed out that the once accepted course of the syphilitic infection with chancre, bubo, skin-eruption, &c., is no example of a biological law, though in the past it has been too frequently accepted as such. Cutaneous manifestations are still the most easily observed of all the effects of the syphilitic infection, and so we can usually obtain the length of time which has elapsed between the appearance of the chancre and of the roseola; on the other hand, we know nothing about the time of "incubation of the secondary visceral symptoms," because observations are not easy to make; hence it is scarcely correct to speak about the incubation of the secondary stage. This point of view has been most forcibly expressed by Audry and Lavau [6]: "Il n'y a pas de seconde incubation; qui voit son chancre a sa vérole." "La syphilis est générale et viscérale du jour où on l'aperçoit."

McIntosh and Fildes [43] have also forcibly voiced this point of view: "The term 'primary' period is strictly a misnomer. There is no primary period from the pathological point of view. A lesion,

indeed, usually occurs at the point of inoculation, but this lesion is merely an incident in the incubation period of the acute symptoms. Its occurrence is more or less accidental, and, as is now well known, is often absent." The same authors also lay stress upon the fact that the spirochætes within a few days after inoculation may be found in the blood and in the internal organs. "The virus is, therefore, generalized long before the appearance of the primary sore, and this lesion cannot be looked upon as denoting a 'period of local eruption.'"

If these authors are right in their point of view, the term "primary period" loses much of its importance, but, nevertheless, its use may be justified as indicating a comparatively early stage in the infection, and it is in this way that throughout this paper I have used the term. Generally speaking a syphilitic chancre with a negative Wassermann reaction in the serum indicates a less advanced stage in the infection as compared with a chancre and a positive Wassermann reaction in the serum, for the Wassermann reaction is usually positive as soon as the roseola appears. Boas, however, has recorded three cases of secondary eruption in which the positive Wassermann reaction only appeared after the roseolar eruption had been present for some time, and Bang and With have recorded four similar cases [7]. In this connexion it is noteworthy that a negative Herman and Perutz reaction indicates an even earlier stage of the infection; hence this reaction has at least some prognostic value.[1]

Finger, in his *Handbuch der Geschlechtskrankheiten* [27], has related several instances of syphilis sine exanthemate, and Hugo Müller [46] has recorded an interesting case of syphilitic chancre and positive Wassermann reaction, in which without any specific treatment both disappeared and no cutaneous eruption was ever seen. C. Stern [55] states as the result of his observations: "Ein erheblichen Prozentsatz der Syphilisfälle bekommt überhaupt keine Sekundärerscheinungen (Rezidive) oder, wie Lange es ausdrückt, die Infection kann sich in jedem Stadium auch dem allerersten erschöpfen." Yet even if this author is right, and personally I think he is, in his observations, his conclusions seem a little too sweeping.

[1] On a comparatively large material, Bang and With [7] have confirmed the observation that the Herman and Perutz reaction becomes positive at an earlier period than the Wassermann reaction. Among fifty-three untreated cases of "primary" sore the former reaction was positive in twenty eight and the latter in fourteen only. It is of course a considerable drawback to the interpretation of the reaction that 2 per cent. of control cases give the Herman and Perutz reaction, and that, like the Wassermann reaction, it may be negative in the secondary period.

With these facts before us it seems to me scarcely possible, in cases of typical venereal ulcerations, to exclude syphilis as a diagnosis because no secondary eruption was observed and because the Wassermann reaction was only obtained on one or two occasions, a point of view urged by Blumenthal and several other German authors. Between them, Blumenthal [18], Alexander [1] and Gutmann [32] have published the finding of a positive Wassermann reaction in five cases of soft chancre and in two cases of non-venereal ulcer. In all these cases the Wassermann reaction, however, was transitory, but well-marked as well as weak reactions were observed. In one instance of venereal ulcer with a strongly positive Wassermann reaction no inguinal bubo was observed, but in the four other cases of venereal ulcers and in the two cases of non-venereal ulcers buboes were present (Fönss [28]). Fönss has also published one case showing a venereal ulcer and a Wassermann reaction incompletely positive (0·2-55), and I myself have recently seen a woman with venereal ulcerations who gave a similar reaction (0·2-60). All these authors have accepted this evidence as sufficient for them to declare that a positive Wassermann reaction sometimes occurs in cases of non-syphilitic ulcerations of the skin. The Wassermann reaction is not truly specific, for it appears in, for example, the ulcerations of leprosy; only further observations can show whether it cannot also be set up by other forms of ulceration of the skin. On the other hand, the following observations have convinced me that a positive Wassermann reaction in the cases of venereal ulcer is much more suggestive of syphilis than it is in other diseases, and that the finding of a positive Wassermann reaction in such cases demands a course of antisyphilitic treatment just as definitely as does the presence of a typical primary sore:—

(1) Observations upon several cases have shown that gangrenous ulceration of the penis has retarded the development, if not entirely suppressed the formation, of a syphilitic eruption (Rasch [49], and Andersen [4]). Probably venereal ulcerations may have a similar effect.

(2) A large number of patients when seen suffering from late symptoms of syphilis (e.g., tabes dorsalis) have been treated even by observant and reliable practitioners for a soft chancre (cf. Müller [46]).

(3) Thirteen, amongst the 515 control cases of Bang and With, on at least one occasion gave a positive Herman and Perutz reaction; of these thirteen cases one had suffered from an inguinal adenitis diagnosed as tuberculous, and four others from an inguinal bubo probably secondary to a venereal ulcer, and yet only twenty-four patients in the

whole series examined had suffered from venereal ulcer and eight from an inguinal bubo. When discussing these observations we wrote ([8] p. 35): "On saura de la sorte si elle accompagne généralement cette affection, et on ne lui accorderait alors qu'une valeur médiocre au point de vue du diagnostic de la syphilis." At the present time I am inclined to think that the reaction is due to a syphilitic infection suppressed by the other infection.

(4) Only one of my control cases showed as high a cell count as 4·3 lymphocytes per cubic millimetre and only one gave a high B.R.J. test of (2-10), and yet both these patients were suffering from soft chancres and inguinal buboes. In all probability such patients should be regarded as doubtful examples of syphilis and watched accordingly even if no other symptoms of syphilis are present.

Seeing that apparently characteristic soft chancres later on often take on syphilitic characters, and as, moreover, the correct diagnosis and proper anti-syphilitic treatment is often delayed on account of a previous treatment with, e.g., iodoform or carbolic acid, it has been proposed (cf. Hugo Müller) to treat all soft chancres with injections of salvarsan.

The facts detailed above are certainly in favour of this mode of treatment and certainly in each individual case this question ought to be considered. Soft chancres should be regarded as the manifestations of serious disease, and for a long time the patient should be regarded as a potential syphilitic and the Herman-Perutz and the Wassermann tests should be applied at least several times; and, if possible, the cerebrospinal fluid should be examined in all patients suffering from an inguinal bubo, at least when they are in-patients at a hospital.

(4) *Reactions in Secondary Syphilis.*

I have examined the cerebrospinal fluid of 134 patients (55 men and 79 women) at the time of the first secondary syphilitic eruption. The majority of these patients had received no treatment or at most had received only a few inunctions of mercury. In fifteen cases, comprising 6 men and 9 women, the cerebrospinal fluid showed pathological alterations (10·9 per cent. men and 11·4 per cent. women). Twenty-five cases (12 men and 13 women) showed doubtful pathological changes (21·8 per cent. men and 14·2 per cent. women); and if the twenty-four cases of leucoderma are included in the list of secondary manifestations we get a total of pathological changes in the cerebrospinal fluid in 17 per cent. men and 26·6 per cent. women. In five male cases, none of whom had

received any treatment, the number of cells varied from 4·3 to 6·7 per cubic millimetre; in each of these cases the date of infection varied from three to five months previously, and at the time of examination each showed a copious syphilitic eruption. In Case 11 the cells numbered 8 per cubic millimetre and in the unheated fluid the Wassermann reaction was positive. The B.R.J. reaction in all these six cases was normal.

Of these six men showing pathological alterations in the cerebrospinal fluid, five had not been treated and the sixth (Case 17) still showed 20 cells per cubic millimetre after treatment with salvarsan and mercury; but in this case, at a lumbar puncture three weeks previously, bleeding into the lumbar sac had been set up, and possibly this may have had some relation to the high cell count. The cell counts in Cases 12, 14 and 15 were about 10 per cubic millimetre, whilst the values of the B.R.J. were (1·5-25), (2-14) and (3-30). In Cases 13 and 16 the B.R.J. values were (2·5-18) and (4-15) and the cell counts 2·3 and 4 per cubic millimetre respectively. Case 12 was a man, aged 69, who had observed a chancre at the root of the penis about a month after infection; about the same time he developed a hemiplegia with facial paresis and paralysis of the left arm and leg. Was the cerebral lesion of syphilitic origin? The appearance of the nervous manifestations four weeks before the roseola makes this improbable, and against a syphilitic origin we have also the somewhat low cell count. Case 13 showed an affection of the auditory nerve, and the B.R.J. of (2·5-18) makes the diagnosis of its syphilitic nature probable.

The four females who showed a lymphocytosis varying from 4·7 to 8 per cubic millimetre but no increase in the proteid-content, had not been treated and were all suffering from genital condylomata; three of these patients had given birth to syphilitic children. Of the nine females who showed definite pathological changes in the cerebrospinal fluid, only one had received any specific treatment and her fluid showed 13·7 cells per cubic millimetre; the others who were suffering from severe neglected syphilis had either not been treated or had received only a few inunctions of mercury.

In four cases the lymphocytosis was fairly high; Case 18 (12), Case 19 (11), Case 20 (57), Case 22 (64); but in these cases both the Wassermann reaction in the fluid and the B.R.J. reactions were negative. In Cases 21 and 23 the cell counts were 19·7 and 2·1 per cubic millimetre and the B.R.J. (1·5-25) and (2-25) respectively. The W.R.Sp. was positive in two cases only, Cases 24 and 25; in the first

case where the cell count was 19 and the B.R.J. (1-15) the fluid became almost normal after three injections of salvarsan and twenty-three inunctions of mercury. The second patient, in addition to a severe eruption of syphilis on the skin and mucous membranes, showed optic neuritis of the right eye; after four injections of neosalvarsan and twenty-five inunctions of mercury the W.R.Sp. disappeared and the number of lymphocytes fell from 152 to 23·3 per cubic millimetre, whilst the B.R.J. was "activated" from (3·5-14) to (6-15). After further injections all the reactions became normal.

(5) *Reactions in previously treated Secondary Syphilis.*

I have examined the cerebrospinal fluid from forty-one patients who had been treated previously for syphilis and who at the time of examination still showed secondary eruptions: in six cases or 14·5 per cent. the fluid showed pathological changes. If the thirteen cases with leucoderma are considered with these, we get positive reactions in eight out of fifty-four cases and more or less definite pathological changes in fourteen other cases. Fifteen out of the twenty-one males showed normal reactions in the fluid. In three cases there was a cellular count of about 5 cells per cubic millimetre and B.R.J. values of (1-20), (2-20) and (0-15). In Case 43 the cells numbered 2 per cubic millimetre and the B.R.J. was (3-30), in Case 44, 4·7 cells and B.R.J. (3-10), and in Case 45 11 cells and B.R.J. (2·5-15) were found.

Sixteen females showed a fluid with normal characters, whilst that of one who had a syphilitic affection of several joints showed a B.R.J. of (1-22) and 2·7 cells per cubic millimetre. A well marked pleocytosis was present in Cases 46 (24 cells per cubic millimetre), 47 (26), 48 (45), and the B.R.J. in these were (3-20), (1·5-18), and (3-10) respectively. In Case 48 alone was the W.R.Sp. positive (0·4-60), but this patient was suffering from a severe headache and other nervous syphilitic manifestations.[1]

(6) *Syphilitic Pigmentation.*

Concerning the exact nature of syphilitic pigmentation as it is termed by most English and French authors, or leucoderma as it is called by German authorities, various views have been expressed. The

[1] In this connexion it may be worthy of note that the majority of cases of syphilitic cerebrospinal meningitis occurring in patients the subjects of secondary syphilis are found in insufficiently treated cases. Gennerich examined eleven cases of relapsing secondary syphilis which had been treated previously and found positive reactions in two cases.

French regard the pigmentation as a primary process, whilst the Germans hold that the affection is always due to an eruption of macular syphilis which may be macro- or only microscopic. Of my series of twenty-four patients, in some pigmentary syphilis occurred alone, in others in association with other secondary manifestations. The spinal fluid was definitely pathological in twelve or 50 per cent. of cases, and if the five cases showing cell counts of 4·7, 5, 6, 6.3, and 7 cells per cubic millimetre be considered as abnormal, although the W.R.Sp. and the B.R.J. reactions were normal, we find that only eight out of twenty-four cases showed no abnormalities in the cerebrospinal fluid.

Among thirteen patients suffering from leucoderma, who had been treated previously, though not very intensely, and now showed a new eruption, in two cases cell-counts of 4·3 and 5 cells per cubic millimetre, and in two other cases counts of 16·7 and 21 cells were found; and yet in all four cases the other reactions were normal. Two additional cases showed slight meningeal manifestations together with leucoderma; the one occurred in a young man who suffered from an ulcerative syphilide, and gave a positive Wassermann reaction (W.R.Sp. + (0-0·6)) in the cerebrospinal fluid with 407 cells and B.R.J. (22-120), and the other in a young female with scars of papules on the external genitalia and slighter reactions in the fluid (W.R.Sp. + (35-1·2)), 29 cells, and B.R.J. (1·5-15). I have also seen a man, whose case is not included in this series, who was suffering from a complete paralysis of the legs and a characteristic syphilitic leucoderma, and yet gave a negative Wassermann reaction in the serum; in this case, unfortunately, the cerebrospinal fluid was not examined.

In several of my cases the pathological reactions in the cerebrospinal fluid were readily influenced by treatment with mercury or salvarsan (e.g., Cases 33 and 34); hence pathological reactions in previously treated cases of syphilis are rare.

If all my cases of leucoderma are taken together, of thirty-nine cases, eight of whom were males, gross abnormalities in the reactions appeared in sixteen cases (six of which gave a W.R.Sp. positive), doubtfully pathological reactions in seven cases, and in sixteen the cerebrospinal fluid was normal. Ravaut, as far as I have been able to ascertain, is the only observer who has examined a fairly large number of patients suffering from pigmentary syphilis. Of his twenty-one cases, all of whom were females, the fluid in five contained 4-6 cells, in eight contained 7-20 cells, and in seven more than 20 cells. Ravaut's cases and my own (together sixty cases), with only seventeen absolutely

normal fluids when compared with my total list of 140 normal fluids in 175 cases of secondary non-pigmentary syphilis, support the view that there is a definite connection between pigmentary syphilis and diseases of the spinal cord, possibly through the sympathetic system.

It is worthy of note that a comparatively large number of the females suffering from pigmentary syphilis had given birth to children. Thus thirteen out of thirty-one females suffering from leucoderma had given birth to syphilitic children, and two other patients were pregnant: whilst, on the other hand, only ten females out of eighty suffering from ordinary secondary syphilis had given birth to children. Nineteen of these thirty-one patients had not been treated, and yet as many as ten had given birth to children and one was with child, and of these eleven females three only showed definite abnormal reactions in the cerebro-spinal fluid. If this interrelation between pregnancy and pigmentary syphilis is borne out after the examination of a larger material, the comparison of pigmentary syphilis with cloasmata uterina may be more than superficial, and in favour of such a view we have the interesting fact that cloasma seems to be dependent upon some function of the sympathetic nervous system. Several authors have demonstrated the fact that vitiligo and scleroderma are sometimes caused by a syphilitic meningitis. The well-known fact that patches of pigmentary syphilis (leucoderma) are most often found where the skin is exposed to light cannot be held as evidence against a central origin of this manifestation. Certainly a kind of syphilitic leucoderma does follow a macular syphilide, and also a form of pigmentary syphilis occurs, though rarely, in the male, rendering the whole question of the origin and nature of pigmentary syphilides complex.

(7) *Further Remarks upon the Reactions in Secondary Syphilis.*

A comparison of the results arrived at by different authors in secondary syphilis has only a limited value, because the methods employed in the testing of the various reactions have varied so widely. Below I give an account of the results obtained by some of the more important authorities.

Marcus [45] examined thirty-three cases of recent syphilis, and in one case only found a positive Wassermann reaction in the cerebro-spinal fluid. Gennerich [30] examined fifty-three cases of secondary syphilis, and found more or less pronounced alterations in the fluids of thirty-two cases; in three cases the Wassermann reaction was positive. The pathological reactions were found in patients who had

received no treatment, and in cases after as many as eight injections of salvarsan. Altmann and Dreyfus [2] examined twenty-one cases of "Syphilis I-II," and found positive reactions in the cerebrospinal fluid of fourteen cases, and among thirty-five cases of "Syphilis II" they found pronounced reactions in twelve cases (W.R.Sp. + in 11), and less definite ones in ten cases. Gutmann [32] out of forty-seven cases with secondary syphilis obtained a positive W.R.Sp. in three cases; in one case only the globulin test of Nonne was positive, and in eighteen pleocytosis occurred. Wile and Stokes' [60] material included sixty-nine cases of secondary syphilis, of which twenty-two showed a normal fluid, whilst forty-seven showed a positive reaction in one of the tests. These authors confirmed the observation of Ravaut that the severe eruptions of syphilis, more especially the follicular and the papular, comparatively frequently showed abnormal products in the cerebrospinal fluid. Of nine cases of roseola five showed abnormal fluids in contrast with eight out of ten cases of follicular, and thirteen out of sixteen cases of papular syphilis.

Ravaut [51] in his classical papers recorded the number of lymphocytes in the cerebrospinal fluid of seventy-eight untreated women; in twenty-five only did he find what he regarded as an absolutely normal fluid with "0-3 lymphocytes par champ d'objectif à immersion." He observed an interesting difference between the fluids from cases showing the varying eruptions of secondary syphilis; among twenty-five cases of roseola and affection of the mucous membranes he obtained fifteen with normal cell-counts and two with more than seven lymphocytes per cubic millimetre; of his ten cases with papular syphilides eight showed more than 7 cells, and of his twenty-one cases of pigmentary syphilis five showed 4-6 cells and eight 7-20, and seven more than 20.

The B.R.J. reaction has only been examined previously by Danish authors. Bisgaard [17] in one out of six cases only got values as high as (2-15). Boas and Lind [20] in one out of five cases found a globulin value as high as two. Boas and Neve [21] were the first to publish a case of secondary syphilis with a B.R.J. (4-50); in another case they found B.R.J. (1-30). The same authors in eighty-two cases of secondary syphilis found twenty-nine (36 per cent.) pathological reactions, and amongst these cases were two of "nerve-relapse"; in a single case of a patient who manifested no nervous symptoms they obtained W.R.Sp. + (0·6-40), lymphocytes 107 per cubic millimetre, and B.R.J. (4-40). They do not state the

number of cases showing pathological values of B.R.J. or pleocytosis, but pleocytosis was the more common abnormality. In two cases at the time of the first eruption the patient complained of headache, and the B.R.J. in the one was (3-20), with 35 cells, and the other (1-20) with 45 cells; in a relapsing case with headache the B.R.J. was (4-30), and the cell-count 103.

If all my 212 cases of secondary syphilis with eruption, the patients with clinically manifest nervous syphilis being excluded, are regarded as a single group, we find: Definite pathological reactions in thirty-five cases, 16·5 per cent.; more or less definite pathological reactions in fifty-six cases, 26·4 per cent.; a definite W.R.Sp. positive in seven cases, 3·3 per cent.; the B.R.J. value pathological in eighteen cases, 3·0 per cent.; and definite pleocytosis in twenty-seven cases, 12·7 per cent.

The percentage of cases showing pleocytosis is rather low compared with the figures arrived at by most of the above-quoted authors, but, as at the Rigshospital lumbar puncture is applied to all syphilitic patients irrespective of symptoms, and as practically all patients complaining of nervous symptoms are excluded, whilst the number of patients examined is large compared with the numbers examined by previous workers, I think that, if the same methods are employed, no greater percentage of pathological reactions can be expected in an average material of secondary syphilis.

Bisgaard [17] suggests that possibly a good many patients showing no nervous symptoms, but with pronounced reactions in the secondary stage, later on develop general paralysis. According to the investigations of Mattauchek and Pilz, only 4·67 per cent. of patients infected with syphilis develop general paralysis; it is therefore evident that only a certain percentage of patients showing pathological alterations in the cerebrospinal fluid later on develop parasyphilitic dementia paralytica; but cases giving all these reactions are not so common that Bisgaard's suggestion can be dismissed. McIntosh and Fildes [43] on different grounds have made it probable that the changes in the cerebrospinal system, which at a later date manifest themselves as tabes dorsalis and dementia paralytica, begin early in the infection.

(8) *The Reactions in Latent Syphilis.*

(A) *Latent syphilis with Wassermann reaction positive in the serum.*—This group includes patients in whom a positive Wassermann reaction in the serum is the only evidence of the latent syphilis. The material is somewhat heterogeneous, for the age of the infection varies,

though it generally was not more than a few years. In six out of forty-one patients (14·6 per cent.) whose syphilis had been treated previously, I found definite pathological changes in the cerebrospinal fluid, and in eleven (26·8 per cent.) the fluid was not quite normal. Twenty-six of these patients were males and fifteen were females. In two men the cells numbered 4·3 per cubic millimetre, and the B.R.J. values were respectively (1-10) and (2-20), and in a third 7·7 cells were present with a B.R.J. of (0-10). In Case 48, on the first occasion, the cell-count was 10, and later fell to 6, but the other reactions were normal. In Case 50 several nervous complaints were present, and the B.R.J. was (3-20), with a cell-count of 3 per cubic millimetre, and in Case 51, who complained of similar symptoms in spite of energetic treatment with neosalvarsan, the cell-count was 7·7 and the B.R.J. (2·5-16). Two females showed a cell-count of 5·7 (B.R.J. 0-15) and 6·3 (B.R.J. 0-10) respectively, whilst pronounced changes were found in three cases: in Case 52 a pleocytosis of 19 cells and B.R.J. (0-12), and in the other two cases the findings were 188 cells, B.R.J. (5-20), W.R.Sp. + (0·3-60), and 75 cells, B.R.J. (3·5-20), W.R.Sp. + (0·6-40).

In addition to these cases I have examined seven specimens from untreated females giving a positive Wassermann reaction and no other symptoms, of whom four had given birth to a syphilitic child. One of these (Case 55) showed seventeen cells per cubic millimetre and the other (Case 54) previously mentioned showed fifty-three cells, B.R.J. (3·5-25) and W.R.Sp. + (1·2-50).

(B) *Latent syphilis with a negative Wassermann reaction in the serum.*—I shall consider all my cases of latent syphilis with a negative Wassermann reaction in the serum as a whole, although this is just as heterogeneous a group as the other; in most cases the infection was of recent origin. I have examined specimens from fifty-three such patients. In three of these (5·6 per cent.) pathological reactions were found, in eight others (13 per cent.) the fluid was not quite normal. Only three males out of thirty-two showed abnormal fluids. In a man, aged 79, suffering from malum coxæ senile, who had been infected with syphilis thirty years before, the cell-count was 6 and the B.R.J. (1-15); in a young man who complained of headache and fatigue the cerebrospinal fluid contained 10·7 cells per cubic millimetre with a B.R.J. (1·5-18) (Case 57), and in another young man who complained of no symptoms whatever, 2 cells per cubic millimetre and B.R.J. (0-8) with a positive Wassermann reaction in the fluid W.R.Sp. + (0·6-20) were found.

Four out of twenty-one females showed doubtful changes in one of

the reactions. In one patient complaining of nervous symptoms 6 cells per cubic millimetre were present and in another similar case 7·6 cells and a B.R.J. (1-10) were found. The specimen of fluid obtained from a woman who suffered from facial paresis and who some months later gave birth to a syphilitic child contained 4 cells per cubic millimetre and showed B.R.J. (2-15). The fluid from a woman, aged 67, suffering from a severe hemiplegia, contained only 1 cell per cubic millimetre but gave a B.R.J. of (1-25). In Case 58 severe pathological changes were present, 58 cells per cubic millimetre, B.R.J. (7-30) and W.R.Sp. + (0·6-60).

(C) *Historical.*—In the literature cases in which *either* positive *or* negative Wassermann reactions were obtained in the serum are referred to equally as examples of "latent syphilis"; nevertheless, I think that a statement upon the findings of previous workers may be of interest. Ravaut examined sixty cases of "old" syphilis and found pleocytosis in a few only. Boas [19] worked through seventeen cases, and in one only, a man who had been treated previously for a "nerve-relapse," found a slightly positive Wassermann reaction to the fluid (W.R.Sp. + 1·0-60). Fildes and McIntosh [26] in seven cases obtained negative W.R.Sp. Gennerich [30] examined a good many cases and divides his material into: *Group A* (of nine cases which had received no treatment previously). In seven of these the reactions in the fluid were more or less pathological; in some of the cases, however, the reactions may possibly have been "provocative."

Group B (of twenty cases which had been treated previously with mercury). In eleven of these cases one or more of the reactions in the cerebrospinal fluid were positive. The reactions were all negative in seven sufficiently treated cases in whose serum a negative Wassermann reaction was also found. The remaining thirteen cases had all been insufficiently treated and the serum reacted more or less positively.

Group C (of thirty-seven cases which had been treated first with mercury and later with salvarsan and generally gave a negative Wassermann reaction in the serum). In twenty-two cases the fluid was normal, but in fifteen one of the reactions at least was positive.

Altmann and Dreyfus [2] examined 104 cases of latent syphilis. In eighty cases the cerebrospinal fluid was normal, and in twenty-four it showed some more or less definite pathological features. Boas and Neve [22] examined twenty-seven cases of latent syphilis, in twenty of which the infection was recent and in seven of older date; as the only abnormalities in the cerebrospinal fluid they found a pleocytosis of

9 cells per cubic millimetre in one case of the former group and of 7 cells per cubic millimetre in a case in the second group.

(9) *The Reactions in Tertiary Syphilis.*

Of cases of tertiary syphilis exhibiting no nervous manifestations I have only examined fifteen males and three females. In two of the males at least one of the reactions showed doubtful pathological changes and in three others the reactions were more or less pathological. In twelve cases all the reactions were normal; seven of these were suffering from limited eruptions on the skin, one other was suffering from a syphilitic orchitis, and a second complained of a perforation of the palate. Four cases of aneurysm of the aorta were examined (three females and one male); in all these the fluid was normal. As, however, an association between tabes dorsalis and dementia paralytica with aneurysm of the aorta is frequent (cf. Cases 91, 106 and 111), it would be expected that an examination of the fluid in a larger number of cases of aortic aneurysm would yield a greater percentage of positive reactions in this fluid. Cell-counts of 6·6 and 8 per cubic millimetre (B.R.J. 1·5-15) and (1-20) were obtained respectively in two cases showing periostitis cranii.

In a patient showing periostitis of the nose and scars of old ulceration of the uvula, consequent upon a syphilitic infection six years previously, the cells numbered 58 per cubic millimetre and the B.R.J. was (4·5-20). In a fourth case (Case 61) suffering from periostitis of the tibia the cell-count was only 2·3 cells per cubic millimetre with a B.R.J. of (2·5-25). Case 60 was punctured twice, on both occasions the cell-count was normal. On February 10 the B.R.J. was (2-10) and on March 31 (2·5-20). At the time of the first puncture he showed a gumma of the palate, and before the second developed parotitis.

Ravaut [51] was one of the first to examine the cerebrospinal fluid from cases of tertiary syphilis. In fourteen patients suffering from an eruption of the skin or mucous membranes but showing no nervous symptoms he never found an increase in the number of the cells. About the same time Funke [29] published his observations on fourteen cases of tertiary syphilis showing no abnormalities of the cerebrospinal fluid. One of Ravaut's patients, who was suffering from a gumma of the leg, showed a well-marked pleocytosis; of seven of his cases suffering from perforation of the palate three showed a marked pleocytosis, two a doubtful and two no increase in the cells in the cerebrospinal fluid; four of his other cases with varying affections

showed no cellular reaction, but in one case of syphilitic orchitis numerous lymphocytes were present. In recent years comparatively few observations upon the reactions in tertiary syphilis have been published and I do not know of any record of a patient giving a positive Wassermann reaction in the cerebrospinal fluid who gave no evidence of nervous manifestations.

Gennerich [30] examined seven cases and found abnormal reactions in two. Boas and Lind [20] amongst two cases found in one 16 lymphocytes and a globulin-value of (3). The Wassermann reaction in the fluid was negative in seven cases examined by Boas, in two by Altmann and in thirty-four by Fildes and McIntosh. Boas and Neve recorded a case suffering from periostitis of the cranium showing 22 cells per cubic millimetre. These results of previous workers and my own observations show that in tertiary syphilis in the absence of nervous symptoms the cerebrospinal fluid is generally normal, yet in cases of periostitis and gummatous ulceration around the mouth alterations in the reactions are not very uncommon.

(10) *The Reactions in Early Hereditary Syphilis.*

In this class of case my material is somewhat small and not very interesting. The ages of the children ranged from about four weeks to twelve months. The W.R.Sp. was only positive in one case, and in this case the fluid was mixed with blood and the blood of the patient was extremely positive (W.R.Ser. + (0·01-40)), and thus this reaction may be neglected; in the seven other cases the W.R.Sp. was negative. In Case 62 the spleen was enlarged and the W.R.Sp. negative, but 13 cells per cubic millimetre and a B.R.J. of (2-28) were found. The twin-sister of this patient suffered from a syphilitic eruption, and thus that this patient suffered from hereditary syphilis can scarcely be doubted, but whether the reactions in the fluid and a pronounced opisthotonos were due to syphilis is less certain. In two other cases lumbar puncture led to a certain amount of bleeding and a pleocytosis of 6 with B.R.J. of (2-10) and (1·5-15). In the remaining four cases the cell-counts varied from 1·3-3·3 and the B.R.J. from (0-8) to (1-15).

If on such a small material any definite conclusions can be drawn, it must be that pronounced reactions in early hereditary syphilis are rare; such conclusions, however, are not substantiated by the records in literature and probably would not be borne out by the examination of a larger material. Ravaut [51] examined the cerebrospinal fluid of eight children born of syphilitic mothers but showing no manifest

symptoms; in one case he found "une réaction moyenne." He examined further twenty cases showing syphilitic eruptions, and in seventeen, twelve of whom showed nervous symptoms, he obtained "une réaction moyenne ou grosse"; the ages of these children varied from ten days to twelve months. It must be further remembered that a syphilitic meningitis has been observed even in stillborn children.

(11) *The Reactions in Late Hereditary Syphilis.*

Specimens from twenty untreated patients, of whom six were males, suffering from active, late hereditary syphilis, were examined. A doubtful reaction (8 cells per cubic millimetre and B.R.J (2-20)), probably due to bleeding, was found in the case of a boy, aged 9, who showed syphilitic nodules all over the body. In two girls (Cases 122 and 123), suffering from juvenile dementia paralytica, all the reactions were strongly positive, and so they were in one boy aged 9, suffering from Little's disease (Case 67b). In three patients suffering from parenchymatous keratitis, and showing no nervous symptoms, more or less definite alterations were found in the fluids: Case 65, 34 cells per cubic millimetre, B.R.J. (0-11); Case 66, 1 cell per cubic millimetre, B.R.J. (0-9) and W.R.Sp. + (0·8-80); Case 67, 53 cells per cubic millimetre, B.R.J. (2·5-10) and W.R.Sp. + (1·0-40).

Six cases with previously treated late hereditary syphilis were examined. In a girl, aged 15, suffering from bilateral arthritis of the knees, 7 cells were counted, and in a second girl, aged 10, complaining of keratitis, 8 cells per cubic millimetre were present, and the B.R.J. was (3-15). In a girl (Case 64) with osteitis of the nasal bone, 53 cells were once found, and in Case 63 with paralysis agitans the cell-count was only 2 and the B.R.J. (2-35).

Of the twenty-six patients, thirteen females and four males were suffering with parenchymatous keratitis, and of these seventeen patients a doubtful reaction was found in one case and definite abnormalities in three cases. In eight of twenty-six cases of late hereditary syphilis definite pathological changes were found, and in two others doubtful changes were present (i.e., 30·8 per cent. definite changes and 38·4 per cent. indefinite and definite changes), and here, even if the three cases with organic nervous manifestations are excluded, the percentage is still high.

In the literature I have only found isolated records of syphilis congenita tarda in which the cerebrospinal fluid had been examined in the absence of definite nervous manifestations. Positive reactions

occurred but rarely, and I have never seen a record of a case like No. 67b. Such findings are not surprising, however, when we remember that one of the important reasons for giving a bad prognosis in cases of late hereditary syphilis is the frequency of the development of an affection of the brain or spinal cord. As cases of latent hereditary syphilis, even when untreated, do not always give a positive Wassermann reaction in the serum, and moreover, as is generally admitted, a positive Wassermann reaction often appears in the cerebrospinal fluid before it appears in the serum, as a means of obtaining evidence in a patient suspected of hereditary syphilis and giving a negative Wassermann reaction in the serum, lumbar puncture ought always to be considered.

(12) *Secondary Syphilis affecting the Central Nervous System.*

In the previous discussion I have already mentioned several instances in which a pathological state of the cerebrospinal fluid had led to the diagnosis of "meningeal irritation" and here I shall only discuss cases in which there were clinical signs of a pathological process in the nervous system.

My material includes fifteen patients whose infection dated back from four months to five years. All these patients had been treated previously but generally insufficiently. In addition to these I have examined two others (Cases 48 and 51) suffering from indefinite nervous manifestations and found at least one of the reactions positive, three cases of early optic neuritis (Cases 7, 25 and 42), of which only one gave positive reactions, and a single case (Case 13) with a slight affection of the eighth nerve.

In only three out of fifteen patients did I find a quite normal cerebrospinal fluid. Of these three cases, Case 70 was suffering from atrophy of the left optic nerve, and Cases 68 and 69 from a neuritis of the auditory nerve. Two other cases with an inflammation of the auditory nerves (Cases 72 and 77), however, showed pronounced abnormal reactions and both were examples of "nerve-relapse" after treatment with salvarsan. The two patients (Cases 71 and 75) who suffered from the sequelæ of a hemiplegia gave definite evidence of abnormalities of the cerebrospinal fluid. In two cases (Cases 80 and 81) showing an active optic neuritis, pleocytosis was pronounced, and in two cases (Cases 78 and 82), combining leucoderma and slight meningeal manifestations, a positive W.R.Sp. was obtained. Case 76 is interesting: four months after infection, a patient, who had been treated with a few injections of hydrargyrum foramidatum for primary sore and bubo,

developed a transverse myelitis; in his cerebrospinal fluid the pleocytosis and protein values were high; the W.R.Sp. was not examined, but in the cerebrospinal fluid the Herman and Perutz reactions were positive. (With [61]).

Although in 1880 Lang called attention to a syphilitic meningitis occurring in secondary syphilis, it was not until a much later date that general interest began to be taken in this topic. This interest increased after Ravaut's demonstration of pleocytosis in early syphilis and became more intense after the findings of cases of "nerve-relapse" in patients who had been insufficiently treated with salvarsan. Accounts of this subject were published in this Journal by Fildes and McIntosh [26], and also by Head and Fearnsides [34] who described many illustrative clinical cases.

(13) *Tertiary Syphilis of the Spinal Cord and Brain.*

The differences between "syphilitic" and "parasyphilitic" lesions of the spinal cord and brain are outside the province of this paper and the reader is referred to the recent able discussion of the subject by McIntosh and Fildes [43]. At first some authors thought that the examination of the cerebrospinal fluid was sufficient for the differential diagnosis of these conditions; other and later observers, however, did not share this opinion and accordingly a vast literature arose. Fildes and McIntosh found the Wassermann reaction inconstant in syphilis of the nervous system, but, like most recent workers, found that this reaction was usually positive in cases of dementia paralytica. In cerebral syphilis the number of cells and the amount of proteid tends to be greater, according to most authors, than in dementia paralytica. Bisgaard in a case of cerebral syphilis found B.R.J. (8-80) and in three cases of cerebrospinal syphilis found B.R.J. values of (8-45), (15-120), and (20-250). As will be realized from the later discussion, Head and Fearnsides [34], Fildes and McIntosh [26] are probably correct when they state that the reactions in the cerebrospinal fluid differ according to the site of the lesion.

I have examined the cerebrospinal fluid in fifteen treated and eight untreated cases of cerebrospinal syphilis and found no differences between the treated and untreated cases. In only three cases (Cases 83, 84, and 85), suffering from slight cerebral symptoms, the cerebrospinal fluid was normal, or almost so; in twenty cases the proteids were increased; in seventeen the number of cells was increased and the Wassermann reaction in the cerebrospinal fluid was positive in twelve cases.

Fildes and McIntosh [26] write: "In untreated cases of cerebrospinal syphilis the reaction in the cerebrospinal fluid varies according to the site of the lesion. When the spinal cord is involved it is positive and usually very strong, but when the spinal cord is not involved it is very inconstant, and when present weak." And, "The explanation of this difference in the reaction in these two groups probably lies in the fact that the sample of the cerebrospinal fluid examined is derived from the lumbar region."

As will be recognized from the following Table IV, my observations upon the material of cerebrospinal syphilis of both the secondary and tertiary stages support this view.

TABLE IV.

		Cerebrospinal fluid normal	Cerebrospinal fluid pathological	Lymphocytosis	B. R. J. +	W. R. Sp. +	Total number examined
The spinal cord not affected	S. II	3	8	8	4 + 4?	3	11
	S. III	3	11	8	11	5	14
Totals		6	19	16	15 + 4?	8	25
The spinal cord affected	S. II	0	4	3	3	4	4
	S. III	0	9	5	9	5	9
Totals		0	13	8	12	9	13

The spinal cord was involved in thirteen cases, and the cerebrospinal fluid in each showed more or less definite pathological changes, generally of rather a pronounced character; in nine instances the Wassermann reaction was positive. On the other hand, of twenty-five cases showing cerebral symptoms only, six specimens of cerebrospinal fluid were completely normal, and in eight the Wassermann reaction was positive. It must be remembered that even if my material and that of the above quoted authors support this statement, the number of cases which have been examined is still small and somewhat heterogeneous; and, moreover, several of the cerebral cases (e.g., Cases 83, 84, 85, 87, and 70) did not give evidence of any active process. Fildes and McIntosh state that "the reaction is present most often in recent cases," and it is still rather doubtful whether the results are greatly influenced by the fact that an affection of one of the cranial nerves is more easily detected than an affection of one of the nerves originating from the spinal cord. In this connexion a survey of my cases in which the cranial nerves were affected may be of some interest. Ravaut [51], in three cases of atrophy of the optic nerve, found a pleocytosis. In my series of cases

an apparently isolated affection of the optic nerve occurred in six; in three of these (Cases 7, 42 and 70) the cerebrospinal fluid was absolutely normal, and in three others (Cases 25, 80 and 87) the reactions were more or less pathological. These reactions were similarly abnormal in Cases 81 and 101 in patients suffering from other cerebral symptoms. Tabes dorsalis and optic neuritis occurred together in four cases (Cases 127, 137, 142 and 143); in one case only (Case 127) the cerebrospinal fluid was normal. In three patients complaining of diplopia (Cases 1, 83 and 85) the reactions in the cerebrospinal fluid were normal or almost so.

An affection of the eighth nerve[1] occurred in eight cases. In two patients the fluids were normal (Cases 68 and 69), in one (Case 13) the B.R.J. was (2·5-18), and in two cases (Cases 72 and 77), after a "nerve relapse," the reactions were grossly abnormal. Cases 130 and 132 suffered from tabes dorsalis, as well as an affection of the auditory nerve, and moderate reactions were obtained, and in Case 97 rather pronounced abnormalities were present.

Fildes and McIntosh [26] carried out experiments on the influence of the inactivation of the cerebrospinal fluid upon the Wassermann reaction and wrote (1913): "We, therefore, conclude that the inactivation of the cerebrospinal fluid does not lead to any material destruction of the reacting substances except in cerebrospinal syphilis, and even in this case the destruction is slight when compared with that which occurs in the serum. In our view this result is explicable on the assumption that the Wassermann body proper is practically unaffected by heat. In those cases, however, in which the syphilitic process is most active (cerebrospinal syphilis) the cerebrospinal fluid contains additional bodies derived from the blood fluids in the form of an acute exudate, and these bodies not only tend to give a stronger Wassermann reaction, as in the case of the more active serum, but are also thermolabile." These authors admit that "this stronger reaction will be to some extent non-specific," but regard this non-specificity as negligible, for "an unheated cerebrospinal fluid does not give a positive Wassermann reaction except in a case of cerebrospinal syphilis." The latter statement is not quite borne out by their control cases. These authors examined forty-two control cases and published the findings on these in support of their views, but

[1] It is interesting to note the small percentage of patients showing signs of any affection of the auditory and optic nerves: as a matter of routine all our syphilitic patients, at least 300 in number, were examined in the otological and ophthalmological departments as regards the functions of the auditory nerve and the appearance of the optic fundi.

amongst their cases are only two of spinal tumours and no cases of tuberculous meningitis. As authors who, like Müller, use unheated serum as a routine in cases of severe consumption sometimes find a positive Wassermann reaction, there is reason to expect that the thermolabile Wassermann bodies may in cases of tuberculous meningitis be found in the cerebrospinal fluid, and the same statement may also hold after a narcosis, but as far as I know no experiments upon this subject have been published. The patient, Case 49, who was probably suffering from dementia paralytica, was punctured under ether narcosis and a positive Wassermann reaction was obtained in the cerebrospinal fluid, and one other case, of a young man with primary syphilis, was punctured under narcosis; but the results in this case were vitiated by an admixture with blood.

In a preliminary note in Danish [61], 1915, I suggested that if Fildes' and McIntosh's views are correct the fraction $\frac{\text{W.R.Sp. active}}{\text{W.R.Sp. inactivated}}$, might possibly be of some value in the differential diagnosis between cerebrospinal syphilis and dementia paralytica. In chronic cases, more especially in dementia paralytica, the value of this ratio should be unity, whilst in cases of acute syphilitic meningitis the number obtained should be greater than one. The results obtained by Dr. Boas upon a number of my cases, however, do not completely bear out this view. In Case 24, complaining of secondary syphilis, the W.R.Sp. was positive (1·2-10), in the heated as well as in the unheated fluid. In Case 11, on the other hand, it was only positive in the unheated fluid, so that the fraction was $\frac{1{\cdot}2\text{-}12\,;\ 0{\cdot}8\text{-}80}{1{\cdot}2\text{-}100}$. In Case 99, complaining of mild meningeal symptoms, the W.R.Sp. was at first $\frac{1{\cdot}2\text{-}16}{1{\cdot}2\text{-}0}$; later the value $\frac{1{\cdot}2\text{-}0}{1{\cdot}2\text{-}25}$ was obtained. These differences, however, are small. Case 97 was suffering from a cerebral meningitis, and after inactivation the W.R.Sp. became negative (1·2-100), but unheated the result was (1·2-10) and (0·8-14). Case 143 was an example of taboparesis, and the values $\frac{0{\cdot}6\text{-}16\,;\ 0{\cdot}4\text{-}60}{0{\cdot}6\text{-}0\,;\ 0{\cdot}4\text{-}16}$ were obtained, and in Case 134, suffering from dementia paralytica, the values were almost identical: $\frac{0{\cdot}4\text{-}16.}{0{\cdot}4\text{-}20}$ These cases thus, in part, support my views, but, on the other hand, Case 124 does not. This patient was suffering from dementia paralytica, and has been treated with numerous injections of neo-

salvarsan. On December 16 the fluid obtained by lumbar puncture was mixed with blood, and he was given intrathecally 4·5 mg. of neo-salvarsan. On December 22 the W.R.Sp. inactivated was negative (1·0), but the W.R.Sp. active was positive (1·0-0) and (0·6-60). On January 4 and 11 the results were $\frac{(1·2\text{-}0)\ (0·6\text{-}10)}{(1·2\text{-}50)}$ and $\frac{0·6\text{-}0}{0.6\text{-}20}$, and on February 7 *both* reactions with 1·2 c.c. of fluids were negative. If on this series of observations any general conclusion be possible, it must be that the reaction is generally stronger in the unheated than in the heated cerebrospinal fluid in cases of cerebrospinal syphilis.

(14) *Dementia Paralytica.*

I have made observations upon eleven cases of dementia paralytica where the diagnosis was fairly certain, and upon nine more doubtful cases; in all the cerebrospinal fluid showed abnormal reactions, and I shall treat them as forming a single group. In all the twenty cases pleocytosis was present, but occasionally its degree was small (e.g., Cases 112, 113 and 123). Bisgaard found pleocytosis in 85 per cent. of ninety-three cases, and Nonne and Rehm obtained an excess of cells in 97-98 per cent. In two of my cases (Cases 121 and 124) the Wassermann reaction in the serum was negative, or almost so, probably due to recent energetic treatment of the syphilis. Boas found the Wassermann reaction positive in 100 per cent. of 243 cases, but in one case obtained a negative reaction in the serum after treatment with mercury and salvarsan. In Case 108 the diagnosis is not absolutely certain, and so I shall not pay any attention to the negative Wassermann reaction in the serum; but in Case 109, which had received no antisyphilitic treatment, but where the diagnosis is almost certain, the several times repeated finding of a negative reaction in the serum probably forms an exception to Boas' rule.

In all my cases the Wassermann reaction in the cerebrospinal fluid was positive. In twenty cases Fildes and McIntosh obtained positive results in this fluid, but Plaut found nine negatives amongst 276 cases, and Boas twelve out of 189 when using 1·0 c.c. of the fluid. Boas is of the opinion that the finding of a negative Wassermann reaction in the cerebrospinal fluid is in favour of a diagnosis of cerebral syphilis, but the observations of Fildes, McIntosh and myself do not completely bear out this view (cf. the previous section).

Ross and Jones [54] found their reaction positive in all their cases

of dementia paralytica. Turner [57] examined seventy-eight cases and found a negative reaction in two cases only. Boyd [24] amongst eight cases of general paralysis or taboparesis found in seven cases a positive reaction in a dilution of one in four, and once a reaction in a dilution of one in two.

Bisgaard examined his reaction in 110 cases: the ammonium sulphate fraction was positive in 107 cases or 97 per cent. In 102 cases (93 per cent.) the value of the nitric acid fraction was greater than 20 and in ninety-eight it was greater than 25. In three cases the values were within normal limits, though rather high (2-15), (2-17·5), and (2-20). Bisgaard found that the ammonium sulphate values in all except three cases were higher than the nitric acid values; the values in the three exceptions are (2-20), (2-32·5), and (8-80). Other values obtained by Bisgaard were (4-15), (20-35), (45-85). The highest values for the nitric acid test were (15-140). All my cases, with the exception of Case 111 with a B.R.J. of (2·5-25), showed high or fairly high values with the nitric acid test as well as a comparatively high globulin fraction.

(15) *Tabes Dorsalis.*

When we compare the various reactions in the cerebrospinal fluid in cases of tabes dorsalis and of dementia paralytica we find that abnormalities are much more frequent in the latter disease, and we also observe that in tabes dorsalis the fluid sometimes appears quite normal. This is rather curious when we remember that in the cases of the pure brain lesions of secondary and tertiary syphilis the reactions are less frequent than in cases showing an affection of the spinal cord, and that, on the other hand, by most modern authors tabes[1] dorsalis is regarded as a result of a chronic meningitis (McIntosh and Fildes [43]).

A priori we should expect that the cases which do not show pathological alterations in the cerebrospinal fluid are those of long standing, free from active symptoms and non-progressive, and this view seems to be confirmed by observations. Such cases, moreover, often show a negative Wassermann reaction in the serum and have often received much previous treatment.

According to Bisgaard's [15] survey of the literature in tabes dorsalis

[1] Here I think it is worthy of note that the Danish pathologist Carl Lange [37] in 1872 set forth convincing facts and observations in support of the theory that the pathological alterations, which are characteristic of tabes dorsalis, are caused by a chronic meningitis, but that the paper in which this is stated is almost unknown outside the Scandinavian countries.

pleocytosis occurs less frequently than in cases of dementia paralytica, but when found is usually more pronounced. Boas and Neve [22] observed in ten cases of old-standing tabes dorsalis a normal cell-count in eight cases, and in the other two cases found 8 and 10 cells respectively. In seventeen recent cases of tabes dorsalis a definite pleocytosis was found in eleven, 8 cells were found twice, and in four the cell-count was normal. I have counted the cells in nineteen of my cases; in eleven a pleocytosis varying from 10·3 to 123 cells per cubic millimetre was present, in five the cell-count was normal and in three from 5-6·7 cells were found. In Case 140 at the second puncture a pleocytosis was the only pathological change in the cerebro-spinal fluid.

Most authors, in a fairly large percentage of their cases, have found an increase in the total quantity of proteids. Turner [57] in a single case found the Ross-Jones reaction negative, and Boyd [24], on the other hand, found values as high as from 10 to 13 in two cases. Bisgaard in the only two cases which he had examined (1913) found (0-15) and (1-19). Boas and Neve, since the publication of my preliminary note, have recorded the B.R.J. reaction in ten cases of old-standing tabes, but found no pathological values. The value (2-6) was found in Case 24 and (2-10) in Case 28. In their nineteen cases of tabes with recent developments of symptoms the B.R.J. was positive thirteen times and normal six times. The highest value for the nitric acid fraction was found in Case 11 with B.R.J. (4-70); the highest value for the ammonium sulphate fraction was five observed in the formulæ (5-20), (5-40), (5-50) and (5-60).

In six untreated cases of tabes the B.R.J. was abnormal in five, and in thirteen previously treated cases abnormal values were found in ten. The records varied from (4-22), (8-44), (10-45) to (13-60).

Fildes and McIntosh [26] have examined the Wassermann reaction in the cerebrospinal fluid of twenty-four cases and have twice obtained a negative result. Bing and Trier [11] found positive reactions in five cases and negative in four, and Boas and Neve found W.R.Sp. negative in ten cases of old-standing tabes. In twenty cases of recent tabes dorsalis Bing and Trier found a W.R.Sp. + sixteen times and W.R.Sp. − four times. In my nineteen cases the W.R.Sp. was positive ten times and negative in nine cases. In their nineteen cases Boas and Neve found the Wassermann reaction positive as the most common abnormality, whilst in mine an abnormal B.R.J. was the commonest abnormality. Amongst Boas and Neve's eighteen recent

cases, in nine all the reactions were positive, and at least one of the reactions was positive in seventeen, and amongst my cases all the reactions were positive in nine and at least one of the reactions positive in fifteen. Three of Boas and Neve's patients had not been treated and the B.R.J. was positive once only, yet the W.R.Sp. was positive in all.

Three of my own patients had received no previous treatment, and in all the reactions were positive with the exception of the cell-count in Case 138, which was five per cubic millimetre. Cases 142 and 143, which showed intense reactions, were probably suffering from taboparesis. In Table IX, p. 455, are given the results of the examination of the various reactions and the number of positive results in the cases of Boas and Neve and of my own.

(16) *On the Relation between the Wassermann Reaction and the Proteid.*

Bisgaard, by a somewhat elaborate method, obtained a fairly constant relation between the ammonium sulphate fraction and the Wassermann reaction in the cerebrospinal fluid, and accordingly thought that the Wassermann bodies must be connected with one of the proteids in this fraction [14]. Klien on Bisgaard's material found a certain connection between the Wassermann reaction and the nitric acid fraction [36]. Zaloziecki, however [63], does not accept the conclusions, and I think rightly so, concerning the Wassermann bodies and the globulin fraction. Zaloziecki thinks that it is more probable that the Wassermann bodies are closely related to the proteid fraction precipitated by colloidal gold, as first pointed out by Lange [38] in 1912. Certainly with Bisgaard we may accept the statement that a positive W.R.Sp. generally occurs at the same time as a well-marked B.R.J., but many exceptions are found. In six cases—Case 5 with 0·5-20, W.R.Sp. 1·0-60; Case 24 with 1-15, W.R.Sp. 0·8-70; Case 40 with 2-20, W.R.Sp. 1·2-70; Case 57 with 0-8, W.R.Sp. 0·6-60; Case 82 with 1·5-15, W.R.Sp. 1·2-35; Case 66 with 0-9, W.R.Sp. 0·8-80—a normal B.R.J. was associated with a more or less definite W.R.Sp. In Cases 5 and 66 the ammonium sulphate value was 0, and in Case 111 with B.R.J. (2·5-25), but with a strongly positive W.R.Sp. (0·1-25), and Bisgaard's case with B.R.J. (2-32·5), and W.R.Sp. 0·6 + and Boas and Neve's [22] case with W.R.Sp. + and B.R.J. normal, are similar. In Boas and Neve's Case 5 (p. 162) B.R.J. (1-10) is combined with a W.R.Sp. + (0·3-60),

and their Case 17 B.R.J. (1-20) was associated with W.R.Sp. + (0·2-20).

(17) *Concluding Remarks upon the B.R.J. Reaction.*

As one of his main conclusions Bisgaard stated that "general paralysis is characterized in the cerebrospinal fluid by comparatively low nitric acid values associated with comparatively high ammonium sulphate values," and the results which he himself obtained admirably support this generalization. Out of 106 cases of dementia paralytica 104 showed the first fraction more or less increased as compared with the second and in the other two cases his findings were (2-32·5) and (8-80). Moreover, the figures which he obtained in cases of acute meningitis, of tuberculous meningitis and of tumours were, on the whole, in favour of his statement, but in two out of four cases of "nervous syphilis" the values (8-45) and (15-120) were recorded. Bisgaard also pointed out that the nitric acid values are generally ten times as great as those of the ammonium sulphate fraction and that the ratio 1:10 may be regarded as the normal one. Amongst my own material, if we collect together cases showing the first figure of the ratio of 3 or a smaller number, the proportion 1:10 is found in four cases, the nitric acid figure is proportionately larger than this in nine cases (largest difference (2·5-40)) whilst the globulin fraction is proportionately the greater in forty-two cases. The cases where the globulin figure was larger than 3 numbered thirty-five cases, and in all, except Case 92 with B.R.J. (10-140), the ammonium sulphate was proportionately most increased. Thus a comparatively high globulin value is found not only in dementia paralytica, but also in other types of syphilitic affections, and, as I have already pointed out, such values are found occasionally even in cases of cerebral tumours. But, even if it must be admitted that comparatively high globulin values are not characteristic alone of the cerebrospinal fluid of cases of dementia paralytica, possibly Bisgaard's generalization may be correct, that values like 1 : 4, or 1 : 3 for the ratio $\frac{\text{globulin}}{\text{albumin}}$ are characteristic of dementia paralytica, whilst a value 1 : 5 or a smaller fraction than this is of relatively small diagnostic importance in this disease. Certainly in cases of tumour high values like 1 : 4 were never obtained, the greatest value (1 : 5) occurred in Case 11 (Table III, p. 415). In three cases (Cases 36, 37, and 48) suffering from secondary syphilis the values of the ratio $\frac{\text{globulin}}{\text{albumin}}$ were 1 : 3, 1 : 2·5, and 1 : 3, but these figures do not disprove Bisgaard's generalization, for

possibly these cases might later on develop dementia paralytica. On the other hand, several of my cases of late nervous syphilis, which did not show any signs of dementia paralytica, gave the ratios of ammonium sulphate to nitric acid fractions of 1 : 3 or 1 : 4 (e.g., Cases 67b, 90, 93, 94, 97, 102 and 104), so that these formulæ cannot be regarded as characterizing dementia paralytica only; but of course autopsy alone could prove or disprove whether parasyphilitic changes were or were not present in the brains of these patients. In five of my cases, and in a large percentage of Bisgaard's cases, the fractional ratio in dementia paralytica equalled 1 : 3 or 1 : 4, and such a finding is therefore in favour of this diagnosis.

Unfortunately I have so far only examined the fluid from a single case of tuberculous meningitis, and here the B.R.J. was (15-115). Bisgaard examined specimens from nine such cases and obtained values like (1-17·5), (1-50), (3-65) and (10-65). The few cases which I have seen have convinced me that a diagnosis of tuberculous meningitis is not infrequently made in cases really suffering from chronic syphilitic meningitis, and I should like to urge that in all such cases the Wassermann test ought to be applied both to the blood and to the cerebrospinal fluid, and that in the cerebrospinal fluid tubercle bacilli should be carefully sought before any certain opinion as to the nature of the case is given.

Chapter IV.—The Influence of Antisyphilitic Treatment upon the various Reactions in the Cerebrospinal Fluid.

(1) *The Influence of Treatment upon the Cerebrospinal Fluid in Cases of Syphilis showing no Nervous Manifestations.*

In a previous section of this paper I have shown how far my own observations fit in with Gennerich's statements concerning the provocative effect which salvarsan produces in the cerebrospinal fluid on the various reactions in cases of "primary syphilis."

I have only examined the fluid from nineteen cases of "secondary syphilis" which, prior to lumbar puncture, had been treated with salvarsan, and thus my material is too small to allow of sweeping generalizations. Ten of the nineteen cases exhibited no leucoderma. Two specimens showed no abnormalities of the fluid after thirty inunctions of mercury and the injection of 1·5 grm. of salvarsan, and a third after 1 grm. of salvarsan. Four cases (Cases 12, 24, 25 and 46) showed

a considerable improvement in the degree of abnormality of a previously present pathological reaction, but in three cases (Cases 11, 17 and 26) a certain degree of lymphocytosis was still present after a more or less energetic treatment. In eight cases in which leucoderma was present the reactions were all favourably influenced by the treatment given, which in general was not very intensive, and in a single case only (Case 39) did any marked exacerbation in the B.R.J. occur after two injections of neosalvarsan. Probably the provocative effect in this case was not due to the direct effect of the neosalvarsan, but rather to the hæmorrhagic encephalitis from which the patient died a few days later. (Cf. Head and Fearnsides [34], Case 183, p. 13.)

I have also examined two specimens from cases of latent syphilis; in one of these (Case 51) certain indefinite nervous manifestations were present, and on examination after several injections of neosalvarsan all the reactions in the cerebrospinal fluid were still slightly pathological; in the second the reactions were influenced favourably by the treatment given.

Judged by my thirteen cases of secondary and two cases of primary syphilis, the reactions in the cerebrospinal fluid in patients showing no nervous symptoms or signs are fairly readily influenced by treatment with mercury or (and) salvarsan. In eight cases a more or less severe lymphocytosis disappeared completely, or almost completely; in three cases, in which no lymphocytosis was present, the cell-count after four to six weeks' treatment remained practically unaltered, and in four cases the cell-count fell rapidly after treatment.

The B.R.J. reaction before treatment was normal or almost normal in six cases, and in nine others after treatment became normal or almost normal. In Case 25, after treatment with twenty-five inunctions of mercury and 1·5 grm. of neosalvarsan, the B.R.J. reaction was changed from (3·5-14) to (6-15) and at the same time the other reactions in the cerebrospinal fluid became less definitely abnormal; at a somewhat later examination all the reactions proved normal.

A slightly positive Wassermann reaction in the cerebrospinal fluid was found six times; after a single injection of neosalvarsan in all cases this reaction became negative.

Thus treatment rapidly influences the reactions in the cerebrospinal fluid from cases of early syphilis, but my observations do not support Gennerich's statement that salvarsan frequently produces an exacerbation in the reactions; for if this generalization had been correct we should have expected that in Cases 29, 36 and 54 after treatment the reactions

TABLE V.

ILLUSTRATES THE INFLUENCE OF ANTISYPHILITIC TREATMENT UPON THE DIFFERENT REACTIONS IN CASES WITH NO NERVOUS SYMPTOMS.

No.	Diagnosis	Date	Cells	B.R.J.	W.R. Sp.	Treatment with Neosalvarsan: Hg. inunctions	Number of injections	Grm.	Infus. sarsaparilla	Date	Cells	B.R.J.	W.R. Sp.	Previous treatment with Hg. As.	Age	Sex
6	S. I.	28.12	14	1-10	– (1·2)	40	4	2·85	..	7.4	5	0·9	– (1·2)	0	25	♂
10	S. I.	14.4	21	1·20	– (1·2)	c. 20	—	—	..	1.10	2	0·10	– (1·0)	+ +	18	♂
12	S. II. sequelæ hemiplegiæ sin.	24.11	11·6	2·30	– (1·2)	30	4	2·70	..	7.1	3.3	1·5-25	– (1·0)	0	69	♂
24	S. II.	23.8	19	1·15	1·2-10	23	3	1·35	..	18.9	6·5	1·20	– (1·2)	0	19	♀
25	S. II.	1.3	152	3·5-14	1·2-50	50	7	3·30	..	22.4	5·3	1·5-20	– (1·0)	0	21	♀
28	S. II. + leucoderma ..	2.4	5	2·5-40	– (1·2)	30	4	2·10	..	6.5	4·7	2·25	– (1·2)	0	39	♂
29	,, ,, ..	16.10	7·3	2·5-10	– (1·2)	6	1	0·90	..	30.11	7·7	1·10	– (1·0)	0	23	♂
32	,, ,, ..	11.3	34·7	3·15	– (1·2)	28	3	1·65	..	6.4	3·1	0·10	– (1·2)	0	20	♀
33	,, ,, ..	10.12	4·7	2·22	1·2-45	28	3	1·80	..	6.1	1.7	0·5-15	– (1·2)	0	36	♀
34	,, ,, (fere universal.)	13.12	45	3·19	– (1·2)	17	3	2·10	..	6.1	6	0·15	– (1·2)	0	27	♀
36	,, ,, sclerodactyli	28.9	78	4·5-12	0·8 60	28	2	0·45	..	28.10	16·3	2·10	– (1·0)	0	26	♀
38	,, ,, iritis ..	7.1	39	1·12	– (1·0)	23	3	1·65	..	3.2	8·7	1·10	– (1·0)	0	26	♀
40	S. II. (recidiv.) + leucoderma	18.10	56	2·20	1·2 70	18	4	2·10	..	18.11	16·7	1·14	– (1·2)	+	20	♀
46	S. II. recidiv.	6.12	24	3·20	– (1·2)	25	4	2·15	..	25.2	3·1	1·15	– (1·2)	+ +	18	♀
54	S. latens	25.9.13	53	3·5-25	1·2-50	44	2	0·75	..	6.11	10·7	2·22	– (1·2)	0	23	♀
	,, ...	2.12.14	75	3·20	0·6-40	..	1	0·60	20	13.1	22	2·15	– (1·0)	+ +	—	—
64	S. congenita tard.	2.8	53	1·15	– (1·2)	..	2	0·30	..	24.9	3·3	0·10	– (1·0)	+ +	9	♀
66	,, ,, ...	9.2	1	0·9	0·8-80	40	..	..	..	24.3	2·3	0·10	– (1·2)	0	11	♀
67	,, ,, ...	10.2	53	2·5-10	1·0-40	31	..	..	..	15.3	54	4·5-25	+0·6-40	0	6	♀

* In cases where salvarsan was injected, I have given the value in neosalvarsan equivalent (1·5 = 1).

would have been stronger, when in fact weaker reactions were actually observed.

In hereditary syphilis without nervous symptoms the lymphocytosis disappeared in Case 64, and a weak W.R.Sp. became in Case 66 negative after a small amount of treatment. On the other hand, in Case 67, after treatment with thirty-one inunctions of mercury both the B.R.J. and the W.R.Sp. became distinctly stronger, but the definite lymphocytosis after the same treatment remained unaltered.

(2) *The Influence of Treatment upon the Various Reactions in Cases of "Secondary" Syphilis showing Nervous Manifestations.*

Many writers have discussed the influence of antisyphilitic treatment in cases of so-called "nerve-relapse," but far less has been written upon the question of the effects of treatment on straightforward cases of nervous manifestations in the early months after infection. G. Dreyfus [25] examined the fluids from twenty-four cases of syphilis of the brain in patients who had been treated previously; he found that a single injection of salvarsan is often sufficient to cause the disappearance of the clinical symptoms, and that it is more difficult to render the cerebrospinal fluid normal, but unfortunately he has not given the details of his cases. He suggested that the finding of a positive reaction after treatment has been given makes a new attack of nervous symptoms probable, and that on the other hand the finding of a normal fluid gives a certain guarantee against such a relapse. If this assumption of Dreyfus be correct my Cases 76, 78 and 79 are threatened with a relapse; but that the generalization is too wide is shown by a consideration of the facts in these cases. Case 76 was an example of a severe attack of meningo-myelitis occurring about four months after infection. He was treated with 1·8 grm. of salvarsan; the clinical symptoms almost disappeared, the cell-count fell from 883 to 37 per cubic millimetre, and the B.R.J. from (13-30) to (2-28). Case 78 tells a similar story; after treatment with 4·35 grm. of neosalvarsan, the slight meningeal symptoms disappeared but the cerebrospinal fluid only slowly became normal. In Case 54 the cerebrospinal fluid was at first distinctly pathological; after a few injections this became normal, but soon the fluid became again abnormal and showed more definite changes than had been present before the first injections. In Case 82 the patient complained of slight nervous symptoms; after the first set of injections of neosalvarsan the W.R.Sp. became more positive for a time and the number of cells per cubic millimetre increased; later, after treatment with more salvarsan

and mercury, the number of cells fell, the W.R.Sp. disappeared, whilst the B.R.J., which had never been increased, remained unaltered; at a still later date an exacerbation of clinical symptoms occurred, and the B.R.J. rose to (5-20), whilst the cell-count and W.R.Sp. remained normal. Case 72 is a typical example of a "nerve-relapse" affecting the facial and auditory nerves; after treatment the symptoms almost disappeared, and yet for a considerable time the cerebrospinal fluid did not become normal; no new manifestations developed, and six months, and again fourteen months after the inception of treatment, examinations showed that the cerebrospinal fluid was normal. Purves Stewart [56] has published a similar case of gummatous meningitis (neuro-recidive) in a man whose syphilis dated back ten months. "The cerebrospinal fluid showed an enormous pleocytosis amounting to 459 cells per cubic millimetre, with strongly positive globulin and Wassermann reactions; after treatment with mercury and six injections of salvarsan (0·3 grm.) within ten weeks the lymphocytosis receded to 7·9 cells per cubic millimetre, and the Wassermann and globulin reactions became negative." Boas and Neve [21] have examined two similar cases. The first showed, after treatment with calomel, a neuritis optica as evidence of a nerve-relapse; the W.R.Sp. was + (0·1-20), the cells numbered 768 per cubic millimetre, and the B.R.J. value was (2-40); after treatment with ten injections (0·10 grm.) of salicylate of mercury the W.R.Sp. was + (1·0-60), the cell-count 150, and the B.R.J. (2-30). The second was one of syphilitic meningitis which had been treated with mercury and salvarsan; the W.R.Sp. was + (0·6-40), the cell-count 720, and the B.R.J. (4-50); after treatment with fifty inunctions of mercury the W.R.Sp. became negative (1·0-100), the cell-count 8, and the B.R.J. (4-40).

(3) *The Influence of Treatment upon the Various Reactions in Cases of "Tertiary" Syphilis showing Nervous Manifestations.*

Many observations upon the clinical effects of anti-syphilitic treatment upon late syphilis of the brain and spinal cord have been published, but relatively few observations upon the coincident changes in the various reactions have been recorded. Dreyfus examined the cerebrospinal fluids from 125 cases of "cerebrospinal syphilis"; when the reaction in the fluid was positive, after treatment an improvement in the clinical symptoms was usually observed, but in three cases only did the positive reaction become negative. As one of his conclusions he stated that treatment does not favourably influence cases of cerebrospinal syphilis, except when there is evidence either of syphilitic

endarteritis or of an affection of the vestibular root of the eighth nerve, when the cerebrospinal fluid reacts negatively to the various tests. The work of Fildes, McIntosh, Head and Fearnsides and my own observations show that the Wassermann reaction is comparatively less pronounced when the brain only is affected, and as Dreyfus did not analyse his cases from this point of view, I think some consideration of my results might prove useful.

Fildes and McIntosh found that "the positive Wassermann reaction in the cerebrospinal fluid of cases of acute and chronic syphilis of the central nervous system is rapidly influenced by specific treatment." In two cases the reaction disappeared within nine months after treatment with 1·5 and 2·7 grammes of neosalvarsan respectively, and in two other cases it was diminished within four months under treatment with 2·4 and 2·7 grammes of neosalvarsan. Boas and Neve [22] examined four cases of late cerebral syphilis; in one case where the W.R.Sp. was negative the cell-count fell from 30 to 2 and the B.R.J. from (4-50) to (2-10) in the course of a year after treatment with numerous inunctions of mercury. My own observations seem to suggest that the different reactions are somewhat more difficult to influence in tertiary than in secondary syphilis, but against this generalization we find that in Case 99 and to a less degree in Case 104, after a moderate amount of treatment with mercury and neosalvarsan, the reactions rapidly become normal. In Case 104 the clinical manifestations of meningitis hypertrophica cervicalis almost completely disappeared after a moderate amount of treatment and the Wassermann reaction and the cell-count fell to normal whilst the B.R.J. was less altered; at the autopsy some months later, anatomical signs of the old cervical meningitis were still present.

In eight of the twelve cases at least one of the reactions was favourably influenced and none were intensified, whilst the clinical symptoms generally diminished; four of the cases were somewhat inefficiently treated, and in two (Cases 98 and 67b) the reactions were little altered, and in the other two (Cases 91 and 101) the reactions were influenced in different ways. (See Table VI, p. 450, for details of the reactions and treatment.) If each of the reactions is considered seriatim, we find that in eight cases the number of cells diminished, in one (Case 67b) was unaltered and in one (Case 101) increased. The B.R.J. value fell in ten out of twelve cases, but increased in two (Cases 98 and 67b). The degree of positivity of the Wassermann reaction decreased in eight of ten cases, in four the reaction became

TABLE VI.

To illustrate the Influence of Antisyphilitic Treatment upon the Different Reactions in Sixteen Cases of Syphilis Cerebrospinalis.

No.	Diagnosis	Date of puncture	Cells	B.R.J.	W.R.Sp.	Hg.	Neosalvarsan*		Hectine	Date of puncture	Cells	B.R.J.	W.R.Sp.	Previous treatment with		Age	Sex
						Number of injections	Number of injections	Centigram.	Grm.					Hg.	As.		
72	Neuritis nervi facial. S. II.	31.3	103	(?)	− (0·6)	+	..	..	0·20+10	16.10	2	0·13	− (1·0)	+	+	20	♂
76	Meningo-myelitis. S. II. ..	28.2	883	13·90	..	..	(?)	245	..	24.4	37	2·28	− (1·2)	+	..	21	♂
78	Meningitis spinalis. S. II.	19.8	407	22·120	0·6-0 0·7-2	+	8	435	..	10.10	24	6·20	0·4-40	+	..	32	♂
82	Mening. spinalis. S. II. ..	15 4	29	1.5-15	1·2-35	34	6	210	..	2.7	3	1·12	− (1·2)	+	..	30	♀
88	Meningitis basis cerebri ..	23.11	6·7	5·40	− (1·0)	30	3	195	..	3.1	5·3	3·23	− (1·2)	+	..	37	♂
91	Sequel. hemiplegiæ dext...	17.7	6	4·30	0·6-70	..	4	225	..	23.8	9	2·25	0·6-10	+	..	49	♂
94	Mening. cervic. spin. ..	24.12	150	5·19	0·6-0	50	6	345	..	4.3	19·3	3·9	1·0-60	−	..	36	♂
95	Mening. myelitis	19.1	187	3·25	0·4-10	..	3	160	..	4.3	44	3·10	0·6 40	+	..	46	♂
97	Neur. acustic. A.C. ..	3.12	86	10·80	0·6-0	24	..	..	J.K.	7.1	62·3	3·5-30	− (1·0)	−	..	49	♀
98	Sequel. hemiplegiæ ..	4.2	87	3·40	− (1·2)	35	2	80	..	12.3	76	4·50	− (1·2)	−	..	19	♀
99	Dementia	15.1	147	10·65	1·0-30	50	3	165	..	30.4	5	1·5-22	− (1·2)	+	..	46	♀
101	Sequel. hemiplegiæ ..	5.2	12·3	7.5-45	1·2-20	+	4	125	..	15.3	35·3	6·25	− (1·2)	+	..	38	♀
102	Meningo-encephalitis ..	4.3	12·3	8·30	0·1-0	32	4	150	..	7.4	10·7	4·15	0·6-0	−	..	50	♀
103	Meningo-encephalitis ..	17.3	218	9·50	0·01-0	15	3	90	..	8.4	52·3	5·12	0·4-20	+	..	29	♀
104	Mening. cervic. hypert. ..	30.3	100	17·70	0·6-10	50	5	180	..	9.7	0·6	1·5 30	− (1·2)	+	..	37	♀
67B	Morbus Little. syph. cong.	6.5	15·7	5·20	0·6-0	+	..	..	0·20+26	3.7	16·7	5·5·30	0·1-60	−	..	9	♂

* In cases in which salvarsan was injected I have given the value in terms of neosalvarsan equivalent (1·5 = 1).

The Wassermann reaction in the fluid decreased in eight cases; in four cases it became negative and in Cases 91 and 67B it increased. I think it is of some interest to note that the B.R.J. in Case 88 later became (1—20) and that the W.R.Sp. in Case 91, after a fresh attack of hemiplegia one and a-half year later, was negative. In Case 97 at a puncture half a year previously the W.R.Sp. was negative.

negative and in two cases (91 and 67b) the positive reaction became more pronounced.

The B.R.J. in Case 88 at a later date became (1-20), and the W.R.Sp. in Case 91, one and a half years later after a new attack of hemiplegia, was negative. The fluid of Case 97 had reacted negatively to the Wassermann test at the time of a puncture six months before.

(4) *The Influence of Antisyphilitic Treatment upon the Various Reactions in Cases of Dementia Paralytica.*

In order to be able to estimate the effects of antisyphilitic treatment in cases of dementia paralytica, knowledge of the normal fluctuations in the cerebrospinal fluid is very desirable. Fildes and McIntosh [26] have pointed out that variations in the reactions without treatment may occur on account of "natural protective processes without any active medical intervention." Several investigators have devoted their attention to the variations in the contents of the cerebrospinal fluids obtained from cases of dementia paralytica, and found that one or other of the reactions may be at one examination positive, at another negative. Bisgaard found that in most cases the amount of proteid is fairly constant even after the lapse of several months: for example, he gives B.R.J., 18, ii, 1910 (2-15); 26, x, 1910 (4-15); 15, xii, 1911 (2-20); and in another case he observed 8, iii, 1910 (5-35); 31, x, 1910 (2-15). The fluctuations however do not always seem to be dependent upon the well-known clinical remissions in the disease; for example, Edwin Goodall [31] writes: "From these observations it appears that there is no correlation between the reaction and a state of remission, a positive reaction being obtained in this state as often as a negative, and the reaction varying in a given case." Leredde [41] has devoted particular attention to the effects of antisyphilitic treatment in cases of dementia paralytica. He recorded thirteen cases, in several of which both the symptoms and the W.R. in the serum were influenced favourably, but did not make systematic observations upon the cerebrospinal fluid. Purves Stewart [56] treated seven cases of dementia paralytica with injections of salvarsan or neosalvarsan both intravenously and intrathecally, and writes that: "Before coming to definite conclusions we require numerous and prolonged observations over a large series of cases." With this statement I heartily concur, but nevertheless the weekly examinations of all the reactions in his seven cases bear out his further remark that:

"In every one of the cases of general paralysis in the foregoing tables it will be observed that the lymphocytosis of the cerebrospinal fluid diminished; in three of them the Wassermann reaction disappeared

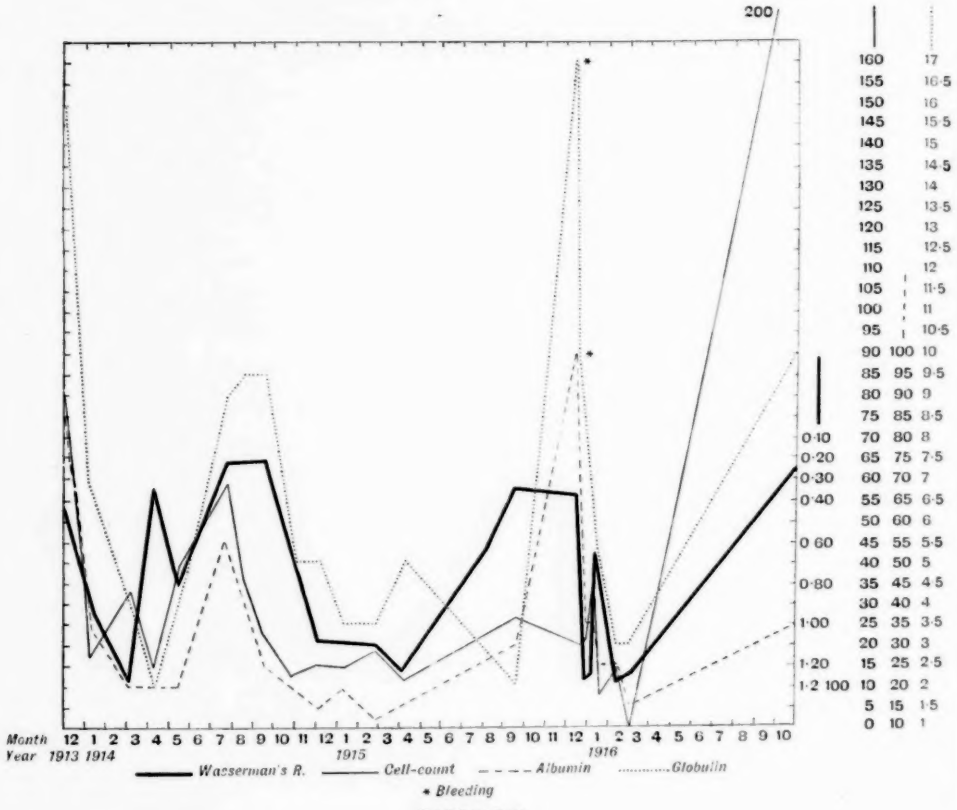

TABLE VII.

GRAPHIC ACCOUNT OF THE REACTIONS IN CASE 124.

The values for the Wassermann reactions are only relative, since the reaction was sometimes done with 1·0 and sometimes with 1·2 c c. as the maximum amount of fluid; it seems rather difficult to decide whether W.R.Sp. (0·2—40) or (0·3—0) is the larger, but I think the values given are sufficiently exact for comparison with the three other reactions. The W.R.Sp. in August, 1914, was only made with 0·6 c.c. fluid.

from the blood; in the cerebrospinal fluid the Wassermann reaction usually became less marked, but in only one case did it disappear." The globulin reaction generally diminished.

I have treated seven cases with mercury and intravenous injections

of salvarsan or neosalvarsan, and even if the treatment has not been so systematic as that given by Purves Stewart, and even if the number of injections given in several of the cases was smaller than our present knowledge indicates, I think that my records possess some value on account of the quantitative measurements of the proteids and on account of the long observation and energetic treatment given to one of the cases. From my material it may be stated that in six out of seven cases the lymphocytosis diminished from a high pathological level to a more or less normal count (in Case 124, for example, the cell-count fell from 80 in November, 1913, to 10·3 per c.mm. in April, 1915). In five cases the B.R.J. diminished, in two in rather an irregular fashion (Cases 121 and 124); in Case 123, on the other hand, the value was practically unaltered by treatment, and in Case 116 the proteid content, probably as an exacerbation on account of the treatment, increased. The Wassermann reaction, in contrast with the cell-count and the B.R.J. reaction, changed in a more irregular fashion, but for a short period in all this reaction was influenced favourably. (See Table VIII, p. 454.)

Case 124 was scarcely a typical one, but the patient was examined more systematically and over a longer period than the others. The cerebrospinal fluid was examined on twenty-seven occasions. He received numerous injections of mercury, 21 grm. of neosalvarsan in twenty-nine injections, and 3·4 grm. of salvarsan in six injections. The examinations showed that during the first two months after the inception of treatment all the reactions were much diminished, then all the reactions began to increase. The globulin value was, except at the time of the last puncture, always relatively higher than the albumin value. At the time of one of the last examinations of the cerebrospinal fluid the mental state of the patient was unsatisfactory. Later he failed both mentally and physically, and eventually died about three years after his first injection. Two and a half months before death the reactions were B.R.J. (10-35), W.R.Sp. 0·2-20 and cells 200. The diagnosis of dementia paralytica was confirmed at the autopsy. (See Table VII, p. 452.)

For my intrathecal injections I used at first 4·5 mgm. of neosalvarsan dissolved in distilled water; later, I gave intrathecal injections of 6, 7, 5 and 9 mgm. Under the treatment neither the mental nor the physical state of the patient was improved, and unfortunately after the last injection incontinence of urine set in. Tzanck and Marcorelles [58] have also observed incontinence of urine after intrathecal injections of salvarsan.

TABLE VIII.

To illustrate the Influence of Antisyphilitic Treatment upon the Different Reactions in Dementia Paralytica and Tabes Dorsalis.

No.	Diagnosis	Date of puncture	Cells	B.R.J.	W.R. Sp.	Number of injections with Hg.	Neo-salvarsan: Number of injections	Neo-salvarsan: Centigramme	Hectine: Grm.	Infusion sarsaparille	Date of puncture	Cells	B.R.J.	W.R. Sp.	Previous treatment with: Hg.	Previous treatment with: As.	Age	Sex
105	Observation for dement. par. ..	2.2.14	32	7-50	0·8-0	20	..	..	..	..	12.8.15	70	3·15	0·4-40	–	–	62	♂
109	,, ,, ,, ..	24.4	20	?-70	0·6-45	+	..	..	0·20	37	15.5	40	13-80	– (0·6)	–	..	49	♀
112	,, ,, ,, ..	12.2	10·3	14-60	0·1-60	20	4	210	+20	..	12.3	7·7	8 18	0·2-60	+	..	50	♀
116	Dementia paralytica	15.1	26·3	11-75	0·4-20	27	3	175	..	..	17.2	13·7	20-70	0·4 0	+	..	41	♂
118	,, ,, ...	21.2	87·3	9-50	0·6-10	39	5	285	..	..	14.4	8·7	5-25	0·6-90	–	..	43	♂
119	,, ,, ...	17.6	132	20-65	0·05-20	26	3	135	..	..	18.7	18·3	12-50	1·0-60	+	..	29	♂
121	,, ,, ...	30.9	20	10-35	0·1-0	30	2	510	..	..	16.3	2	4·5-15	0·6-20	+	..	55	♂
122	,, ,, S. cong. ..	18.11	117	20-80	0·1-10	31	3	135	..	..	10.2	8	11-30	0·1 0	–	..	25	♀
123	,, ,, ,, ..	11.3	11·3	8·5-30	0·2 40	22	4	135	..	..	9.4	4	9-15	0·6-20	–	..	16	♀
124	,, ,, ,, ..	23.11.13	80	16-85	0·4-20	+	28	21·75	..	..	12.4.15	10·3	5-15	– (1·0)	+	..	36	♂
132	Tabes dorsalis	19.3	5	4-15	– (1·2)	21	6	300	..	..	15.6	8·1	5-30	– (1·2)	+	..	51	♀
134	,, ,, ...	8.4	123	4-22	0·4-0	34	8	390	..	..	21.10	7·3	4·5 18	0·3-20	+	..	49	♀
137	,, ,, ...	31.10	38·7	5-19	0·6-20	73	12	695	..	..	26.6	1·7	1 15	– (1·0)	–	..	54	♂
138	,, ,, ...	20.11	5	4·5-15	1·0-40	72	11	660	..	..	27.3	3	2·5 15	– (1·0)	–	..	34	♀
142	,, ,, obser. f. derm. par.	15.8	88	13-60	0·4-12	30	3	135	..	..	17.3	33	8·5-35	– (1·2)	+	..	62	♂
143	,, ,, ,, ,, ,,	2.9	23	8-44	0·4-16	36	..	..	0·20	..	1.10	21	6-27	0·4-30	+	..	42	♂
144	,, ,, ,, ,, ,,	4.9	25	10-45	0·4-60	34	7	345	+20	..	30.11	12	4·5-15	0·4-60	–	..	42	♂

* In cases in which salvarsan was injected, I have given the corresponding values in terms of neo-salvarsan equivalent (1·5 = 1).

TABLE IX.

	Reaction in the Cerebrospinal Fluid						B.R.J. Reaction		Cell Count		W.R. Sp. +	W.R. Sp.+				Summa
	All −		At least one +?		At least one +							Cells		B.R.J.		
	♂	♀	♂	♀	♂	♀	+?	+	V 4 10 Λ	10 Λ		−	+	−	+	
S. I with W.R. Ser. − ..	32	8	1	1	3		1	1	3	1	1	1		1		45
S. I with W.R. Ser. + ..	24	7	3		3				3	3						37
Syphilis I (total) ..	56	15	4	1	6		1	1	6	4	1	1		1		82
S. II first eruption ..	43	66	6	4	6	9	1	7	10	13	2		2	1	1	134
S. II relapse (previously treated)	15	16	3	1	3	3	1	4	4	4	1		1		1	41
Leucoderma :																
Untreated	1	6	1	4	3	9	1	7	7	8	3	1	2	1	2	24
Previously treated ..	1	8	1	1		2			2	2	1?		1?	1?		13
Syphilis II (total) ..	60	96	11	10	12	23	3	18	23	27	7	1	6	3	4	212
S. latens previously treated :																
W.R. Ser. + ...	20	10	3	2	3	3		4	6	4	2		2		2	41
W.R. Ser. −	29	17	1	3	2	1	1	1	2	2	2	1	1	1	1	53
S. latens untreated ..		5				2		1		2	1		1		1	7
Syphilis latens (total) ..	49	32	4	5	5	6	1	6	8	8	5	1	4	1	4	101
Syphilis congenita recens ..	2	2	2		1		1	1	2	1						7
S. cong. tarda :																
Untreated	3	11	1		2	4		5	1	5	4	1	4	1	4	21
Previously treated ..		2		2	1	1		1	2	1						6
Syphilis congenita tarda (total)	3	13	1	2	3	5		6	3	6	4	1	4	1	4	27
Syphilis III	10	3	2	0	3	0		3	2	1						18
Syphilis II nervosa ..	2	1			9	3		7	1	11	6		6	1	5	15
S. III nervosa :																
Untreated		1			2	5		7		7	4		4		4	8
Previously treated ..		1	1	1	8	4	1	12	4	9	7	1	6		7	14
Syphilis III nervosa (total)		2	1	1	10	9	1	19	4	16	11	1	10		11	22
Observ. for dementia paralytica					5	4		9		9	9		9		9	9
Dementia paralytica ..					8	3		11		11	11		11		11	11
Tabes dorsalis :																
Untreated			1		4	1	1	5	2	4	5	1	4		5	6
Previously treated ..	3	1			5	5		10	2	7	6		6		6	14
Tabes dorsalis (total) ..	3	1	1		9	6	1	15	4	11	11	1	10		11	20
Boas and Neve :																
Old standing tabes dorsalis	8		1		1		2		1	1	0					10
Recent tabes dorsalis ..	2				17		1	12	2	11	17	3	11	6	11	19

In their case, after the second and fourth injections incontinence of urine developed. Probably, both in my own case and in that of Tzanck and Marcorelles, the incontinence developed owing to further spread of the disease. Certain of the reactions in the cerebrospinal fluid in Case 124 were probably altered considerably by the bleeding which took place on December 16th, 1915.[1]

(5) *The Influence of Anti-syphilitic Treatment in Cases of Tabes Dorsalis.*

Leredde [41] treated twenty-three cases of tabes dorsalis with intravenous injections of neosalvarsan and obtained satisfactory clinical results, but, unfortunately, did not examine the effects upon the cerebrospinal fluid in a systematic manner. Dreyfus [25] in many of his seventy-seven cases found that under energetic treatment the reactions and also the clinical manifestations were improved, and even found benefit in those patients whose cerebrospinal fluid reacted negatively to the Wassermann test. Becher and Koch [9] in 1914 published a case of tabes dorsalis in which the reactions in the cerebrospinal fluid were examined on several occasions during the course of a year whilst the patient received treatment with salvarsan and mercury. The lymphocytosis was very definitely influenced and, in a more irregular fashion and to a less degree, the proteid reactions and the Wassermann reaction were similarly affected. The most systematic investigations which I have seen were published by Purves Stewart [56]. He examined in 1914 the effect of intrathecal injections of salvarsan upon the reactions and the symptoms in eleven cases of tabes dorsalis; in ten cases the cell-counts fell to a greater or less extent after from three to five injections of salvarsanized serum and in most cases the globulin and Wassermann reactions became less abnormal. In his Case 10 the cells increased from 10·1 to 18·3 per c.mm. after five injections of salvarsan.

I have examined the influence of treatment in eight cases of tabes dorsalis. Case 142 was only treated with hectine and inunctions of mercury, and in Case 126 the reactions both before and after treatment with two injections of salvarsan were completely normal. The lymphocytosis diminished gradually in three cases (Cases 134, 137 and 144),

[1] After this paper was originally sent in (April, 1916) there appeared a full discussion by Walker and Haller [59] of the effects produced by intrathecal injections in seventy-five cases of syphilis of the nervous system.

was unaltered in Case 143, and diminished in Case 142 from 88 to 33 per c.mm. after treatment, later to relapse and yield 78 cells per c.mm. The B.R.J. gradually became less definite in five cases (Cases 137, 138, 142, 143, 144), but was practically unaltered in Cases 132 and 134. The Wassermann reaction in the cerebrospinal fluid was very variable in Cases 134 and 142, but on the whole tended to become more positive; in Cases 143 and 144 the reaction was not affected by treatment and in Cases 137 and 138 became negative. In Case 138 the W.R.Sp. remained negative for three months, but then, possibly as an exacerbation, after three injections of salvarsan it once more became positive. In one case (Case 138) only was there real improvement in the clinical manifestations, but in several others some amelioration occurred.

From the above Sections (4) and (5) it will be realized that in "parasyphilis" the cell-count is the reaction which is most easily influenced by anti-syphilitic treatment and that the W.R.Sp. is the reaction which is most resistant to treatment. In several cases it seemed to me that the first injection of salvarsan or neosalvarsan produced more effect upon the reactions than did the subsequent injections, and this would agree with the views of McIntosh and Fildes, who wrote: "In pure parasyphilis we assume a lesion practically confined to the nerve structures and resistant to treatment. In most cases of parasyphilis, however, the lesions are not so restricted and actively involve the vascular structures. This element of parasyphilis will be curable." The considerations which McIntosh and Fildes advance in favour of their statement that parasyphilis is resistant to treatment do not seem to be quite convincing. Before the questions of whether it is possible by treatment to arrest the degeneration of the nerve-cells and fibres at the stage to which it has attained, and whether we can hope to check the spreading of the virus to other nerve elements or not, can be decided, systematic observation, both clinical and serological, of a long series of cases treated intravenously, intrathecally and both intravenously and intrathecally, is needed. In the assumption that lesions which involve the vascular structures are more easily curable these authors are probably right; in this way may possibly be explained the comparative rapidity with which the lymphocytosis and the B.R.J. values sometimes decrease at the commencement of treatment.

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